Rules for the Manufacture, Testing and Certification of Materials

July 2016

Lloyd's Register

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A guide to the Rules

and published requirements

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Introduction

The Rules are published as a complete set.

Rules updating

The Rules are generally published annually and changed through a system of Notices between releases.

July 2016

■ *Section 1* Scope

1.1 General

1.1.1 Materials used for the construction, conversion, modification or repair of ships, other marine structures and associated machinery which are classed or are intended for classification by Lloyd's Register (hereinafter referred to as LR), are to be manufactured, tested and inspected in accordance with these Rules.

1.1.2 Wrought, cast and extruded materials are to comply with the requirements of *Ch 1 General Requirements* and *Ch 2 Testing Procedures for Metallic Materials*, and the appropriate specific requirements of *Ch 3 Rolled Steel Plates, Strip, Sections and Bars* of these Rules. Mooring and anchoring equipment is to comply with the requirements of *Ch 1 General Requirements* and *Ch 2 Testing Procedures for Metallic Materials*, and the appropriate specific requirements of *Ch 10 Equipment for Mooring and Anchoring*. Manufacturers of these materials must be approved by LR according to the requirements in *Ch 1, 2 Approval and survey requirements* or *Ch 1, 3 Certification of materials*. Only those materials within a manufacturer's scope of approval may be used.

1.1.3 Welding consumables are to comply with the requirements of *Ch 11 Approval of Welding Consumables* of these Rules.

1.1.4 Where welding is used for the construction, conversion, modification or repair of ships, other marine structures and associated machinery which are classed or are intended for classification by LR, welding qualifications and tests shall be performed according to *Ch 12 Welding Qualifications* of these Rules. All welding shall be performed according to *Ch 13 Requirements for Welded Construction* of these Rules.

1.1.5 Plastics materials are to comply with the requirements of *Ch 14 Plastics Materials and other Non-Metallic Materials* of these Rules.

1.1.6 Coatings, corrosion prevention systems and their components are to comply with the requirements of *Ch 15 Corrosion Prevention*.

1.1.7 The materials and components which are to comply with these requirements for the purposes of classification are defined in the relevant Rules dealing with design and construction.

■ *Section 2* Approval and survey requirements

2.1 Approval and survey requirements – General

2.1.1 Marine materials manufactured in accordance with *Ch 3 Rolled Steel Plates, Strip, Sections and Bars* of these Rules are to be made at works which have been approved by LR for the type and grade of product being supplied.

2.1.2 Materials manufactured in accordance with *Ch 3 Rolled Steel Plates, Strip, Sections and Bars* of these Rules are to be manufactured, tested and inspected under Survey according to the requirements of one of the following two schemes:

(a) The Materials Survey Scheme, *see Ch 1, 2.3 Materials Survey Scheme*.

(b) The Materials Quality Scheme, *see Ch 1, 2.4 Materials Quality Scheme*.

2.1.3 For the purposes of survey, LR Surveyors are to be allowed access to all relevant parts of the works, and are to be provided with the necessary facilities and information to enable them to verify that the manufacture is being carried out in accordance with the approved procedures. Facilities are also to be provided for the selection of test material, the witnessing of mechanical tests and the examination of materials, as required by these Rules.

2.1.4 Where a production process, testing or examination of materials is sub-contracted, this must be with the approval of LR. Surveyors are to be allowed access to the sub-contractor's premises in order to conduct Surveys according to the requirements of these Rules.

2.1.5 Products manufactured in accordance with *Ch 11 Approval of Welding Consumables*, *Ch 14 Plastics Materials and other Non-Metallic Materials* and *Ch 15, 2 Coatings* and *Ch 15, 3 Corrosion Resistant Steels* of *Ch 15 Corrosion Prevention* are to be approved in accordance with the requirements therein. For these materials, approval is given for a specific product on a type approval basis, rather than the approved manufacturer/survey arrangements applied to materials covered by *Ch 3 Rolled Steel Plates, Strip, Sections and Bars* to *Ch 10 Equipment for Mooring and Anchoring*.

2.2 LR Approval – General

2.2.1 Unless specifically stated in other Chapters of these Rules, all LR approvals apply to materials used in applications intended for marine service, as described in *Ch 1, 1.1 General*.

2.2.2 The procedures for application for approval of manufacturers and products, the details of the information to be supplied by the manufacturer, and the test programme to be conducted on the products are given in the appropriate book of LR's *Materials and Qualification Procedures for Ships* (MQPS). This is published in the Class Direct section of LR's web site at http://www.lr.org.

2.2.3 LR publishes lists of approved manufacturers and approved products. The lists are published in the Class Direct section of LR's website, http://www.lr.org. The lists are as follows:

- *List of Approved Manufacturers of Materials.*
- *Approved Welding Consumables for Use in Ship Construction.*
- *Lists of Paints, Resins, Reinforcements and Associated Materials.*
- *Lists of Approved Anchors.*

2.2.4 For initial LR approval as an Approved Manufacturer for a particular material, the manufacturer is required to demonstrate to the satisfaction of LR that the necessary manufacturing and testing facilities are available, and are supervised by suitably qualified personnel. A specified programme of tests is to be carried out under the supervision of LR Surveyors, and the results are to be to the satisfaction of LR.

2.2.5 If the results of the initial assessment of the manufacturer, and the test programme are considered satisfactory, the manufacturer will be added to the list of approved manufacturers of materials, and a certificate of approval will be issued to the manufacturer by LR, showing the scope of materials and grades covered by the approval. Initial approval will generally be under the Materials Survey Scheme, *see Ch 1, 2.3 Materials Survey Scheme*.

2.2.6 Approved manufacturers who meet the entry requirements may apply for approval under the Materials Quality Scheme, *see Ch 1, 2.4 Materials Quality Scheme*.

2.2.7 When a manufacturer has more than one works, the manufacturer's approval shall only be valid for the works where the test programme was conducted.

2.2.8 It is the manufacturer's responsibility to advise LR of all changes to the manufacturing process parameters that may affect the application of the material, prior to the adoption of the changes in production. Additional approval tests may be required to maintain the approval.

2.2.9 Maintenance of approval is dependent on the manufacturer continuing to meet the requirements of the applicable sections of these Rules.

2.2.10 Where it is considered that an approved manufacturer is not maintaining its responsibilities to comply with these Rules, the approval may be suspended by LR until such time that agreed corrective and preventive actions are considered to have been satisfactorily carried out. If considered necessary, LR may require that the normal level of testing and inspection is increased.

2.2.11 In all instances, LR will reduce the scope of, or withdraw approval from, a manufacturer where it becomes apparent that the manufacturer is unable to maintain compliance with these Rules or the scope of approval.

2.2.12 Where a manufacturer disagrees with any decisions made with regard to LR approval, they may appeal in writing to LR.

2.2.13 Any documents, data or other information received as part of the approval process will be treated as strictly confidential, and will not be disclosed to any third party, without the manufacturer's prior written consent.

2.2.14 The approved works will be subject to a periodic inspection of all relevant parts of the works, at intervals not exceeding three years. The procedure for this periodic inspection is given in Book B of LR's *Materials and Qualification Procedures for Ships* (MQPS). This periodic inspection is in addition to the regular visits made according to *Ch 1, 2.3 Materials Survey Scheme 2.3.7*.

2.3 Materials Survey Scheme

2.3.1 Materials according to *Ch 3 Rolled Steel Plates, Strip, Sections and Bars* to *Ch 10 Equipment for Mooring and Anchoring* of these Rules and produced under the Materials Survey Scheme will be subject to Direct Survey by an LR Surveyor. The scheme requires the Surveyor to survey and certify all materials according to the requirements of these Rules.

2.3.2 Approved manufacturers are to request a survey of the material by an LR Surveyor, when required. Manufacturers must provide the Surveyor with details of the order, specification and any special conditions additional to the requirements of these Rules.

2.3.3 All mechanical tests required by these Rules are to be witnessed. The Surveyor may allow part of this task to be carried out by a member of the works staff by prior written agreement.

2.3.4 Before final acceptance, all materials are to be submitted to the specified tests and examinations under conditions acceptable to the Surveyor. The results are to comply with the Rules, and all materials are to be to the satisfaction of the Surveyor.

2.3.5 The specified tests and examinations are to be carried out prior to the despatch of finished materials from the manufacturer's works. Where materials are supplied in the rough or unfinished condition, as many as possible of the specified tests are to be carried out by the manufacturer, and any tests or examinations that are not completed are to be carried out under survey at a subsequent stage of manufacture.

2.3.6 In the event of any material proving unsatisfactory during subsequent working, machining or fabrication, such material is to be rejected, notwithstanding any previous certification.

2.3.7 In addition to witnessing test results, the Surveyor is responsible for ensuring that the manufacturing process, inspection, testing, identification and certification are properly conducted. As part of the Materials Survey Scheme, regular visits will be made to all relevant parts of the works, including the subcontractors who are conducting any process which will affect the properties of the final products, to check for compliance against the requirements of these Rules, and to ensure that the manufacturer is maintaining the capability to consistently produce approved materials.

2.3.8 The Surveyor, when satisfied that the material fully meets the requirements of these Rules, will certify the material in accordance with *Ch 1, 3 Certification of materials* and the appropriate Chapter of these Rules.

2.4 Materials Quality Scheme

2.4.1 The manufacturer may apply to be approved under the Materials Quality Scheme where the following requirements are met:

(a) The manufacturer has been approved by LR for a minimum of three years and continues to maintain their LR works approval according to *Ch 1, 2.2 LR Approval – General 2.2.14*; and
(b) The manufacturer has a quality management system, which has been certified as meeting the requirements of ISO 9001 by a certification body recognised by LR, which is one accredited by a member of the International Accreditation Forum; and
(c) The manufacturer has a satisfactory history of quality performance in the manufacture and supply of LR approved materials.

2.4.2 Special consideration may be given to manufacturers who have not been approved under the Materials Survey Scheme, and may be considered onto the Materials Quality Scheme providing:

(a) They have a quality management system which has been certified as meeting the requirements of ISO 9001 by a certification body recognised by LR, which is one accredited by a member of the International Accreditation Forum.
(b) They can demonstrate a history of satisfactory supply of materials which LR deems to be equivalent to those for which approval under the Materials Quality Scheme is requested.

In this case, the initial assessment of the manufacturer will include the product testing regime, as required for initial approval under the Materials Survey Scheme *see Ch 1, 2.2 LR Approval – General 2.2.4*.

2.4.3 The Scheme is based on a Scheme Certification Schedule, made between LR and each individual manufacturer. The schedule will stipulate:

(a) The scope of approved products covered by the approval.

(b) The process route applied by the manufacturer for each approved product.

(c) The arrangements for LR scheme, audits, including scope, frequency, schedule, etc.

(d) Agreed procedures for certification of approved materials.

(e) Information to be supplied periodically to LR by the manufacturer.

(f) Procedures for the use of the scheme mark.

2.4.4 The contents of the Scheme Certification Schedule are to remain confidential between LR and the manufacturer.

2.4.5 The Materials Quality Scheme is based on a technical audit approach, and is designed to complement the quality management systems audits performed to ISO 9001. The role of the Surveyor in scheme audits is to:

(a) Verify that the quality management system is being maintained and audited to the requirements of ISO 9001.

(b) Verify that the requirements of these Rules are being implemented.

(c) Verify that the requirements of this Scheme are being implemented.

(d) Perform Scheme audits, which focus on the technical aspects of the product realisation process, particularly with regard to Rule requirements.

(e) Perform witness testing as required.

(f) Verify the data supplied to LR periodically by the manufacturer as part of the Scheme requirements.

2.4.6 The Materials Quality Scheme may be applied to any approved manufacturer who meets the eligibility requirements, and who applies to be approved under the scheme. If approved under the scheme, the manufacturer's name will appear on the List of Approved Manufacturers published by LR, with an indication that they are approved under this scheme.

2.4.7 The scheme is available to manufacturers producing approved materials according to *Ch 3 Rolled Steel Plates, Strip, Sections and Bars* to *Ch 10 Equipment for Mooring and Anchoring* of these Rules.

2.4.8 The procedures for application for approval for the Materials Quality Scheme are given in Book M of LR's *Materials and Qualification Procedures for Ships* (MQPS).

2.4.9 Where LR is satisfied that the manufacturer meets all of the requirements of the Scheme, and that it is appropriate for the products being manufactured, a Scheme Certification Schedule will be issued, which must be signed by an authorised representative of the manufacturer.

2.4.10 Once the Scheme Certification Schedule has been signed by both parties, LR will issue the manufacturer with a certificate of approval according to the Materials Quality Scheme.

2.4.11 Maintenance of approval will be according to the Scheme Certification Schedule agreed between LR and the manufacturer, and these Rules.

2.4.12 It is the responsibility of the attending Surveyor to perform regular Scheme audits at the manufacturer's works in accordance with the Scheme Certification Schedule, and the requirements of these Rules.

2.4.13 It is not the intention to repeat the audit according to ISO 9001 conducted by the recognised certification body. The Surveyor is, however, to be satisfied that these audits are being conducted effectively. Where appropriate, the Surveyor may conduct a partial audit to ISO 9001 to verify this.

2.4.14 Witness tests may be conducted as part of the Scheme audit. This will involve the selection of material, and the witness of sampling and testing according to the requirements of the appropriate chapter of these Rules. Such witness testing may be on LR grades, or materials which the Surveyor deems to be equivalent (for the purposes of audit testing only).

2.4.15 Once every three years, a full assessment of scheme compliance will be conducted by a Surveyor who is not the regular attending Surveyor. This assessment is in addition to the periodic inspection requirement made according to *Ch 1, 2.2 LR Approval – General 2.2.14*.

2.4.16 In the event of any change which means that the manufacturer no longer meets the requirements for the Materials Quality Scheme (for example the loss of ISO 9001 approval), the Scheme certificate of approval will be revoked. The manufacturer will revert to the Materials Survey Scheme, and will be subject to survey according to that scheme.

Section 3
Certification of materials

3.1 General

3.1.1 All materials subject to these Rules are to be supplied with appropriate certification, as required by the relevant requirements of these Rules. This will normally be an LR certificate or a manufacturer's certificate validated by LR, although a manufacturer's certificate may be accepted where allowed by the relevant requirements of these Rules.

3.1.2 Manufacturers approved under the Materials Quality Scheme are licensed to apply the scheme mark to manufacturer's certificates according to the requirements of the scheme, *see Ch 1, 2.4 Materials Quality Scheme*.

3.1.3 The following certificate types are to be used, (a) and (b) for the Materials Survey Scheme, and (d) for the Materials Quality Scheme:

(a) **LR Certificate**

This type of certificate is issued by LR based on the results of testing and inspection being satisfactorily carried out in accordance with the requirements of these Rules.

(b) **Manufacturer's certificate validated by LR**

A manufacturer's certificate, validated by LR on the basis of inspection and testing carried out by the manufacturer and which is in accordance with the requirements of these Rules, may be accepted. In this case, the certificate will include the following statement:

"We hereby certify that the material has been made by an approved process and satisfactorily tested in accordance with the Rules of Lloyd's Register."

(c) **Manufacturer's certificate**

This type of certificate is issued by the manufacturer based on the results of testing and inspection being satisfactorily carried out in accordance with the requirements of these Rules or the applicable National or International standard. The certificate is to be validated by the manufacturer's authorised representative, independent of the manufacturing department. The certificate will contain a declaration that the products are in compliance with the requirements of these Rules or the applicable National or International standard.

(d) **Manufacturer's certificate issued under the Materials Quality Scheme**

Where a manufacturer is approved according to the Materials Quality Scheme, they will issue manufacturer's certificates bearing the scheme mark. The certificates must also bear the following statement:

"This certificate is issued under the arrangements authorised by Lloyd's Register (operating group) in accordance with the requirements of the Materials Quality Scheme and scheme number MQS ……."

3.1.4 Where these Rules allow for the issue of a manufacturer's certificate for materials, either validated by an LR Surveyor, or bearing the Materials Quality Scheme mark, the manufacturer is to ensure that a copy of the certificate is supplied to LR.

3.2 Materials Survey Scheme

3.2.1 The requirements for certification of materials according to the Materials Survey Scheme are established by the relevant requirements of these Rules.

3.2.2 The manufacturer is to supply the surveyor with any additional customer order requirements that are in addition to the requirements of these Rules, when the request for the issue or validation of the certificate is made.

3.3 Materials Quality Scheme

3.3.1 Part of the certification schedule will include an agreement for the manufacturer to apply the scheme mark to manufacturer's certificates relating to approved products within the scope of approval of the manufacturer.

3.3.2 The use of the scheme mark is governed by the following:

(a) The use of the scheme mark is not transferable. It is only to be used in conjunction with the manufacturer and works name and location shown on the certificate of approval.
(b) The scheme mark must be applied to all manufacturers' certificates relating to approved materials produced under the Scheme.

(c) In no circumstances is the scheme mark to be applied to test certificates relating to non-approved products.
(d) The scheme mark is not to be used in any way which may imply approval for products which are not covered within the manufacturer's scope of approval.
(e) Where a manufacturer is removed or suspended from the scheme, use of the scheme mark must cease immediately.

3.3.3 The certificate as given in *Ch 1, 3.1 General 3.1.3* is to be validated by an authorised representative of the manufacturer. The size and position of the scheme mark and statement on the manufacturer's certificate must be agreed by LR.

3.3.4 Where manufacturers are approved under this scheme, the manufacturer's certificate issued according to these requirements fully meets the materials certification requirements of these Rules.

3.4 Electronic certification

3.4.1 Where these Rules allow the issue of manufacturers' test certificates, under either the Materials Survey Scheme or the Materials Quality Scheme, these may be issued in electronic format provided that:

(a) All tests and inspections have been satisfactorily completed according to the requirements of these Rules.
(b) Procedures are in place to ensure that electronic certificates are only issued according to the requirements of these Rules.
(c) The certification system is subject to regular inspection by the attending Surveyor.
(d) A copy of the electronic certificate is supplied to LR. This copy will be deemed to be the original of the test certificate.

3.4.2 In addition to the requirements of *Ch 1, 3.4 Electronic certification 3.4.1*, for items certified under the Materials Survey Scheme, the LR office stamp and Surveyor's name may be applied electronically. This is only allowed where the Surveyor has access to the results of the relevant tests and inspections, and is able to authorise by access to the electronic system, the application of the LR office stamp and Surveyor's name on the test certificate. The name of the authorising Surveyor is to be the name included on the certificate. The authorisation may be conducted electronically either at the manufacturers' works, or remotely by the Surveyor.

3.4.3 If the LR office stamp and name are being applied electronically according to *Ch 1, 3.4 Electronic certification 3.4.2*, then the manufacturer is to ensure that the Surveyor is provided with all relevant information regarding the customer order, when the request for authorisation is made.

■ *Section 4*
General requirements for manufacture

4.1 General

4.1.1 The following definitions are applicable to these Rules:

Item:	A single forging, casting, plate, tube or other rolled product as delivered.
Piece:	The rolled product from a single slab or billet or from a single ingot if this is rolled directly into plates, strip, sections or bars.
Batch:	A number of similar items or pieces presented as a group for acceptance testing.
Wide Flat:	flat product of a width over 150 mm, up to and including 1250 mm and thickness generally over 4 mm. Edges are square cut, i.e. hot rolled on the four sides. Supplied in lengths, not coils.
Plate/Sheet:	flat rolled product whereby the edges are allowed to deform freely. Supplied flat and generally in square or rectangular shapes with a width of 600 mm or over, but other shapes may also apply.

4.1.2 Where a manufacturer purchases semi-finished products (e.g. slabs) for the purpose of re-processing (e.g. rolling), the manufacturer is to ensure that the materials are from an LR approved manufacturer, and manufactured within the scope of approval of that manufacturer. The aim of chemical analysis, dimensions, surface and internal quality checks are to be agreed

between the manufacturer and purchaser. The semi-finished materials must be supplied with appropriate certification, according to these Rules.

4.1.3 It is the responsibility of the manufacturer to ensure compliance with all relevant aspects of these Rules. All deviations are to be recorded as non-compliances, and brought to the attention of the Surveyor, along with corrective actions taken. Failure to do this is considered to render the material as not complying with these Rules.

4.1.4 The manufacturer is to maintain all test and inspection records required by these Rules for at least seven years. Records are to be made available to LR on request.

4.1.5 Where material is produced which does not meet all aspects of these Rules, the manufacturer may apply to LR for a concession to certify the material as approved. LR will consider each application on a case-by-case basis, although concession will only normally be granted in exceptional circumstances. If the concession is granted, a formal written numbered concession will be issued to the manufacturer. The concession number must be applied to the approval certificate, whether it is an LR certificate or a validated manufacturer's certificate.

4.2 Chemical composition

4.2.1 The ladle analysis used for certification purposes is to be determined after all alloying elements have been added and sufficient time allowed for such additions to equalise throughout the ladle.

4.2.2 The method of taking samples is to ensure that the reported analysis is representative of the cast. In addition, the manufacturer must determine and certify the chemical composition of every heat of material.

4.2.3 Where more than one sample is taken, the method of averaging for the final certificate result and the determination of acceptable variations in composition are to be agreed with the Surveyor.

4.2.4 The chemical composition of ladle samples is to be determined by the manufacturer in an adequately equipped and competently staffed laboratory. The manufacturer's analysis will be accepted, but may be subject to occasional independent checks if required by the Surveyor.

4.2.5 The analysis is to include the content of all the elements detailed in the relevant Sections of the Rules and, where appropriate, the National or International Standard applied.

4.2.6 At the discretion of the Surveyors, a check chemical analysis of suitable samples from products may also be required. These samples are to be taken from the material used for mechanical tests but, where this is not practicable, an alternative procedure for obtaining a representative sample is to be agreed with the manufacturer. For product samples, the permissible limits of deviation from the specified ladle analysis are to be in accordance with an appropriate International or National Standard specification.

4.3 Heat treatment

4.3.1 Materials are to be supplied in the condition specified in, or permitted by, the relevant Chapters of these Rules.

4.3.2 Heat treatment is to be carried out in properly constructed furnaces which are efficiently maintained and have adequate means for control and recording of temperature. The furnace dimensions are to be such as to allow the whole item to be uniformly heated to the necessary temperature. In the case of very large components which require heat treatment, alternative methods will be specially considered.

4.3.3 The manufacturer is to maintain the records, including the temperature charts of all heat treatments for at least seven years.

4.4 Test material

4.4.1 Sufficient test material is to be provided for the preparation of the test specimen detailed in the specific requirements. It is, however, in the interests of manufacturers to provide additional material for any re-tests which may be necessary, as insufficient or unacceptable test material may be a cause for rejection.

4.4.2 The test material is to be representative of the item or batch and is not to be separated until all the specified heat treatment has been completed, except where provision for an alternative procedure is made in subsequent Chapters of these Rules.

4.4.3 All test material is to be selected by the Surveyor or an authorised deputy and identified by suitable markings which are to be maintained during the preparation of the test specimens.

4.5 Mechanical tests

4.5.1 The dimensions, number and direction of test specimens are to be in accordance with the requirements of *Ch 2 Testing Procedures for Metallic Materials* and the specific requirements for the product.

4.5.2 Where Charpy impact tests are required, a set of three test specimens is to be prepared and the average energy value is to comply with the requirements of subsequent Chapters. One individual value may be less than the required average value provided that it is not less than 70 per cent of that value.

4.5.3 In the Rules, mechanical properties are specified in SI units, but alternative units may be used for acceptance testing. In such cases, the specified values are to be converted in accordance with the appropriate conversions given in *Table 1.4.1 Conversions from SI units to metric and Imperial units*. It is preferred that test results be reported in SI units, but alternative units may be used provided that the test certificate gives, in the same units, the equivalent specification values.

Table 1.4.1 Conversions from SI units to metric and Imperial units

1 N/mm^2 or MPa	=	0,102 kgf/mm^2
1 N/mm^2 or MPa	=	0,0647 tonf/in^2
1 N/mm^2 or MPa	=	0,145 x 10^3 lbf/in^2
1J	=	0,102 kgf m
1J	=	0,738 ft lbs
1 kgf/mm^2	=	9,81 N/mm^2 or MPa
1 tonf/in^2	=	15,4 N/mm^2 or MPa
1 lbf/in^2	=	6,89 x 10^{-3} N/mm^2 or MPa
1 kgf m	=	9,81 J
1 ft lbf	=	1,36 J

4.6 Re-test procedures

4.6.1 Re-test procedures are to be in accordance with the requirements of *Ch 2, 1.4 Re-testing procedures*.

4.7 Rectification of defective material

4.7.1 Small surface imperfections may be removed by mechanical means provided that, after such treatment, the dimensions are acceptable, the area is proved free from defects and the rectification has been completed in accordance with any applicable requirements of subsequent Chapters of these Rules and to the satisfaction of the Surveyor.

4.7.2 The repair of defects by welding can be accepted only when permitted by the appropriate specific requirements and provided that the agreement of the Surveyor is obtained before the work is commenced. When a repair has been agreed, it is necessary in all cases to prove by suitable methods of non-destructive examination that the defects have been completely removed before welding is commenced. Welding procedures and inspection on completion of the repair are to be in accordance with the appropriate specific requirements and are to be to the satisfaction of the Surveyor.

4.7.3 Manufacturers wishing to carry out welding work must have at their disposal the necessary workshops, lifting gear, welding equipment, pre-heating, and where necessary annealing facilities and testing devices, as well as certified welders and supervisors to enable them to perform the work properly. Proof shall be furnished to the Surveyor that these conditions are satisfied before welding work begins.

4.8 Identification of materials

4.8.1 The manufacturer is to adopt a system of identification which will enable all finished materials to be traced to the original cast, and the Surveyors are to be given full facilities for tracing the material when required. When any item has been identified by the personal mark of a Surveyor, or his deputy, this is not to be removed until an acceptable new identification mark has been made by a Surveyor. Failure to comply with this condition will render the item liable to rejection.

4.8.2 Before any item is finally accepted it is to be clearly marked by the manufacturer in at least one place with the particulars detailed in the appropriate specific requirements.

4.8.3 Where hard stamps such as the LR brand stamp are issued to manufacturers to carry out the stamping on behalf of LR, the procedure for issue, maintenance and use of stamps is to be agreed in writing.

4.8.4 Hard stamping is to be used except where this may be detrimental to the material, in which case stencilling, painting or electric etching is to be used. Paints used to identify alloy steels are to be free from lead, copper, zinc or tin, i.e. the dried film is not to contain any of these elements in quantities of more than 250 ppm.

4.8.5 Where a number of identical items are securely fastened together in bundles, the manufacturer need only brand the top item of each bundle. Alternatively, a durable label giving the required particulars may be attached to each bundle.

■ *Section 5*
Non-destructive examination

5.1 General NDE requirements

5.1.1 Prior to the final acceptance of materials, surface inspection and verification of dimensions, non-destructive examination is to be carried out in accordance with the requirements detailed in this Section and subsequent Chapters of these Rules.

5.1.2 It is the manufacturer's responsibility for maintaining the required tolerances and making the necessary measurements. Periodic surveys by the Surveyor do not absolve the manufacturer from this responsibility.

5.1.3 When there is visible evidence to doubt the soundness of any material or component, such as flaws in test specimens or suspicious surface marks, the manufacturer is expected to prove the quality of the material by a suitable method.

5.1.4 Acceptance criteria are detailed in subsequent Chapters of these Rules. Alternative specifications may be submitted for consideration, provided they demonstrate equivalence to these Rules.

5.2 Personnel qualifications

5.2.1 The shipyard, fabricator or manufacturer is to ensure that personnel carrying out non-destructive examination or interpreting the results of non-destructive examination are qualified to the appropriate level of a nationally recognised scheme such as ISO 9712, PCN, ACCP or SNT-TC-1A. Level 1 personnel are not permitted to interpret results to Codes or Standards.

5.2.2 When certification of personnel is made on an inhouse basis under a scheme such as SNT-TC-1A, practical examinations are to be relevant to material, product type, joint configuration, material thickness and acceptance criteria of items inspected for Classification purposes.

5.2.3 Personnel qualifications of NDE operators are to be randomly checked by the Surveyor.

5.3 Non-destructive examination methods

5.3.1 Non-destructive examination methods are to comply with the relevant requirements of these Rules.

5.4 Non-destructive examination procedures

5.4.1 All non-destructive examinations are to be carried out to a procedure that is representative of the item under inspection. As a minimum the procedures are to be in accordance with the following:

(a) Procedures are to identify the component to be examined, the NDE method, equipment to be used and the full extent of the examinations including any test restrictions.
(b) Procedures are to specify the qualification and certification requirements of the inspection personnel to be employed.
(c) Procedures are to state the degree of surface preparation required and the methods of preparation to be used before the examinations are made.
(d) Procedures are to state the reference standards for testing and the acceptance criteria to be applied to the results of the inspections.
(e) Procedures are to include the requirement for components to be positively identified and for a datum system or marking system to be applied to ensure repeatability of inspections.
(f) Procedures are to identify any requirements for increasing the extent of applied NDE where defects have been found during spot examination.
(g) Procedures are to identify reporting requirements.
(h) Procedures are to be reviewed by the Surveyor to ensure they are appropriate for the product type.

(i) Procedures for radiography are to specify the acceptable optical density within the area of interest on the radiograph.
(j) The minimum optical density within the area of interest on a radiograph is to be equal to or greater than 2,0 for gamma ray and 1,8 for X-ray. A maximum density of 4,0 is acceptable.
(k) Procedures are to include the method and requirements for equipment calibrations and functional checks.
(l) Procedures are to be approved by an operator qualified to a minimum of Level III in accordance with a recognised standard.
(m) The Surveyor will review procedures for compliance with this Section.

5.4.2 The shipyard, fabricator or manufacturer may submit other Codes or Standards for consideration by LR, providing they are equivalent to these Rules. Where no agreed acceptance standard is in place, the acceptance levels contained in the subsequent Chapters of these Rules are to apply.

5.4.3 In the event that proposed acceptance criteria are not considered to be equivalent to these Rules, the criteria may be submitted for special consideration.

5.5 Non-destructive examination reports

5.5.1 NDE reports are to include all information required to identify how the examination was executed and are to include the following information where appropriate:

(a) Date of test.
(b) Name and qualification of operator with signatures of the operator.
(c) Details of the component identification, description of test location and volume examined.
(d) Heat treatment status.
(e) Weld type, procedure and configuration.
(f) Surface condition.
(g) Test procedure.
(h) Equipment used.
(i) Test results with a map or record of reportable and/or reject indications, giving location, dimensions and nature of indications.
(j) Reference to acceptance criteria and evaluation in accordance to these criteria.
(k) Material type and thickness.
(l) Calibration.

■ *Section 6* References

6.1 General

6.1.1 The location of National and International Standards referenced in these Rules are shown in *Table 1.6.1 List of National and International Standards*.

Table 1.6.1 List of National and International Standards

Rule reference	Standard
Chapter 1 – General Requirements	ISO 9001: 2015 SNT-TC-1A, 2011 ISO 9712:2012

Chapter 2 – Testing Procedures for Metallic Materials	ISO 6892-1: 2009 ISO 6892-2:2009 ISO 185: 2005 ISO 2566-1: 1999 ISO 148-1: 2010 ISO 7500-1: 2004 ISO 6506-1: 2014 ISO 6506-2: 2014 ISO 6506-3: 2014 ISO 6507-1: 2006 ISO 6507-2: 2006 ISO6507-3: 2006 ISO 6508-1: 2015 ASTM E23-Rev C (2012)
Chapter 3 – Rolled Steel Plates, Strip, Sections and Bars	EN 10160: 1999 ASTM A578-07 (2012) ASTM E112 - 2013 ASTM E381-01 (2012) ASTM A255-2010 ISO 7452:2013 ASTM E208-06 (2012) JWES2815
Chapter 4 – Steel Castings	ISO 1161: 1984/Amendment 1: 2007
Chapter 5 – Steel Forgings	ASTM E112 (2013)
Chapter 8 – Aluminium Alloys	ASTM G66 (2013) ASTM G67 (2013)
Chapter 9 – Copper Alloys	ASTM E272-2010 EN 1057: 2006 +A1: 2010
Chapter 10 – Equipment for Mooring and Anchoring	ISO 1704: 2008 ISO 1834: 1999 BS 7160 (R2002) ASTM E112 (2013) ASTM E381-01 (2012) ASTM A255-2010
Chapter 11 – Approval of Welding Consumables	ISO 3690: 2012 ISO 10042: 2005 ASTM G48 - 11
Chapter 12 – Welding Qualifications	ISO 6947: 2011 ISO 5817: 2014 ISO 6520-1: 2007 ISO 6507-1: 2005 ISO 10042: 2005 ASTM G48-11 ISO 25239-3: 2011 ISO 25239-4: 2011

Chapter 13 – Requirements for Welded Construction	ISO 9712:2012 ISO 25239-5: 2011 ISO 6520-1: 2007 SNT TC-1A-2011 AWS D3.6M:2010 ISO 10042: 2005
Chapter 14 – Plastics Materials	ISO 527-2: -2012 ISO 178: 2010 Amd 1:2013 ISO 62: 2008 ISO 75-2: 2013 ISO 604: 2002 ISO 527-4: 1997 ISO 14125: 1998/amd1:2011 ISO 14130: 1997/corr1:2003 ISO 1172: 1996 ISO 1922- 2012 ASTM C273/C273M -11 ASTM C393/C393M -11e1 ISO 845- 2006 ASTM C297/C297M-04 (2010) ISO 844-2014 ISO 180-2000/Amd 2:2013 ASTM D2583-13a BS 2782-10 Method 1001: 1977 ISO 175: 2010

Contents

■ *Section 1*
General requirements for testing

1.1 Preparation of test specimens

1.1.1 The requirements specified below detail all the tests that may be applied to metallic materials. The specific tests and the test specimen types required for each material type, grade and product type are detailed in the subsequent Chapter of these Rules.

1.1.2 Where test material is cut from products by shearing or flame cutting, a reasonable margin is required to allow sufficient material to be removed from the cut edges during machining of the test specimens.

1.1.3 Test specimens are to be prepared in such a manner that they are not subjected to any significant work hardening, cold straining or heating during straightening or machining.

1.1.4 Test samples are not to be removed from the material they represent until heat treatment is complete. For castings in cases where test samples are separately cast, the castings and samples are to be heat treated together.

1.1.5 Dimensional tolerances are to comply with a relevant ISO specification.

1.2 Testing machines

1.2.1 All tests are to be carried out by competent personnel. Testing machines are to be maintained in a satisfactory and accurate condition and are to be recalibrated at approximately annual intervals. This calibration is to be carried out by organisations of standing that have been approved or recognised by a Naval Authority and are to be to the satisfaction of the Surveyor. A record of all calibrations is to be kept available in the test house.

1.2.2 Tensile testing machine load cells are to be calibrated with an accuracy of ± one per cent in accordance with ISO 7500-1 or another recognised National Standard.

1.2.3 Impact tests are to be carried out on Charpy V-notch machines calibrated to ISO 148 or ASTM E23 dependent on the testing machine type. The testing machines are to be calibrated using either a direct or indirect method. Other National Standards equivalent to ISO 148 may be considered.

1.2.4 Hardness testing machines, together with their associated measuring microscopes, are to be directly and indirectly calibrated to ISO 6506-2, 6507-2 or equivalent standards applicable to the type of hardness test. Other National Standards equivalent to ISO 6507-2 and 6506-2 standards may be considered. Routine hardness checks with standard hardness blocks calibrated to ISO 6506-3 or ISO 6507-3 or equivalent are to be carried out at a frequency which demonstrates calibration consistency.

1.3 Discarding of test specimens

1.3.1 If a test specimen fails because of faulty preparation or incorrect operation of the testing machine it may be discarded and replaced by a new test specimen prepared from material adjacent to the original test.

1.3.2 In addition to the discarding of test specimens as indicated in *Ch 2, 1.3 Discarding of test specimens 1.3.1*, a tensile test specimen may also be discarded when the specified minimum elongation is not obtained and the distance between the fracture and the nearest gauge mark is less than one-third of the gauge length.

1.4 Re-testing procedures

1.4.1 Where the result of any test, other than an impact test, does not comply with the requirements, two additional tests of the same type are to be made from the same test sample, or if sufficient material is not available, a further representative sample taken from the item under test. For acceptance of the material, satisfactory results are to be obtained from both of these additional tests.

1.4.2 Where the result of any test taken from a weld procedure approval test, other than an impact test, does not comply with the requirements, two additional tests of the same type are to be made from the same weld test assembly. Where insufficient original welded assembly is available, a new assembly is to be prepared using the same conditions as the original test weld. For acceptance, satisfactory results are to be obtained from both of these additional tests.

1.4.3 Where the result of any test taken from a welding consumable approval test, other than an impact test, does not comply with the requirements, two additional tests of the same type are to be made from the same weld test assembly. Where insufficient original welded assembly is available, a new assembly is to be prepared using welding consumables from the same batch. If the new assembly is made with the same procedure (particularly the same number of runs) as the original assembly, only the duplicate re-test specimens need be prepared and tested. For acceptance of a weld consumable batch, satisfactory results are to be obtained from both of these additional tests.

1.4.4 Where the results from a set of three impact test specimens do not comply with the requirements, an additional set of three impact test specimens may be tested provided that, of the original set tested, not more than two individual values are less than the required average value and, of these, not more than one is less than 70 per cent of this average value. The results obtained are to be combined with the original results to form a new average which, for acceptance, is to be not less than the required average value. Additionally, for these combined results, not more than two individual values are to be less than the required average value and, of these, not more than one is to be less than 70 per cent of this average value.

1.4.5 The additional tests detailed in *Ch 2, 1.4 Re-testing procedures 1.4.1* are, where possible, to be made on material adjacent to the original samples. For castings, where insufficient material remains in the original test samples, the additional test may be made on other test samples representative of the castings. *See also Ch 2, 1.3 Discarding of test specimens* for discarding of test specimens.

1.4.6 When unsatisfactory results are obtained from tests representative of a batch of material, the item or piece from which the tests were taken is to be rejected. The remainder of the material in the batch may be accepted provided that two further items or pieces are selected and tested with satisfactory results. If the tests from one or both or these additional items or pieces give unsatisfactory results, the batch is to be rejected.

1.4.7 When a batch of material is rejected, the remaining items or pieces in the batch may be resubmitted individually for test, and those which give satisfactory results may be accepted.

1.4.8 At the option of the manufacturer, rejected material may be resubmitted as another grade and may then be accepted, provided that the test results comply with the appropriate requirements.

1.4.9 When material which is intended to be supplied in the ‘as-rolled’ or ‘hot-finished’ condition fails test, it may be suitably heat treated and resubmitted for test. Similarly, materials supplied in the heat treated condition may be reheat treated and resubmitted for test. Unless otherwise agreed by the Surveyor, such reheat treatment is to be limited to one repeat of the final heat treatment cycle.

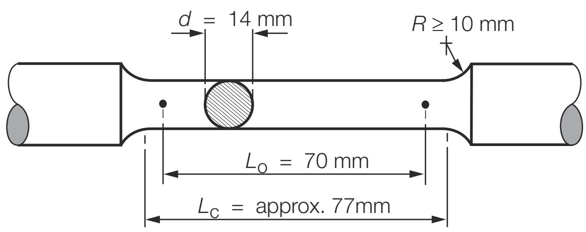
■ Section 2
Tensile tests

2.1 Dimensions of test specimens

2.1.1 Proportional test specimens with a gauge length L_0 of $5,65\sqrt{S_0}$ or $5d$ where S_o is the cross-sectional area, d the diameter and L_C the parallel test length, have been adopted as the standard form of test specimen, and in subsequent Chapters in these Rules the minimum percentage elongation values are given for test specimens of these proportions.

2.1.2 The gauge length is to be greater than 20 mm and may be rounded off to the nearest 5 mm provided that the difference between the adjusted gauge length and the calculated one is less than 10 per cent of the calculated gauge length.

2.1.3 For forgings and castings (excluding those in grey cast iron) proportional test specimens of circular cross-section are to be machined to the dimensions shown in *Figure 2.2.1 Test specimen dimensions for forgings and castings - I*.

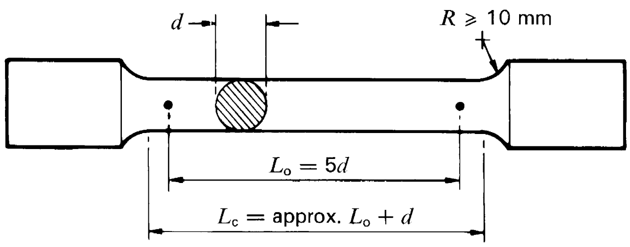


NOTE: For nodular cast iron and materials with a specified elongation less than 10%, $R \geq 20$ mm

Figure 2.2.1 Test specimen dimensions for forgings and castings - I

2.1.4 For hot rolled bars and similar products, the test specimens are to be as in *Figure 2.2.1 Test specimen dimensions for forgings and castings - I*, except that for small sizes they may consist of a suitable length of bar or other product tested in the full cross-section.

2.1.5 As an alternative to *Ch 2, 2.1 Dimensions of test specimens 2.1.3* and *Ch 2, 2.1 Dimensions of test specimens 2.1.4*, proportional or non-proportional test specimens of other dimensions may be used, subject to any requirements for minimum cross-sectional area given in subsequent Chapters of these Rules. Where the size of proportional test specimens is other than as shown in *Figure 2.2.1 Test specimen dimensions for forgings and castings - I*, the general dimensions are to conform with *Figure 2.2.2 Test specimen dimensions for forgings and castings - II and aluminum alloys*.



NOTE For nodular cast iron and materials with a specified elongation less than 10%, $R \geqslant 1,5d$

Figure 2.2.2 Test specimen dimensions for forgings and castings - II and aluminum alloys

2.1.6 For plates, strip and sections, the test specimens are to be machined to the dimensions shown in *Figure 2.2.3 Test specimen dimensions for plates, strip and sections - I and aluminum alloys* or *Figure 2.2.4 Test specimen dimensions for plates,*

strip and sections - II. Where the capacity of the available testing machine is insufficient to allow the use of a test specimen of full thickness, this may be reduced by machining one of the rolled surfaces. Alternatively, for materials over 40 mm thick, test specimens of circular cross-section machined to the dimensions shown in *Figure 2.2.1 Test specimen dimensions for forgings and castings - I* may be used. The axes of these test specimens are to be located at approximately one quarter of the thickness from one of the rolled surfaces.

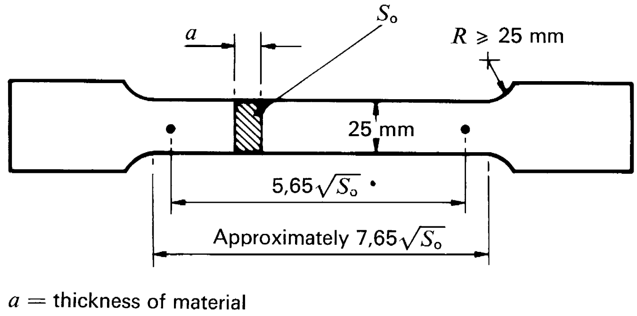


Figure 2.2.3 Test specimen dimensions for plates, strip and sections - I and aluminum alloys

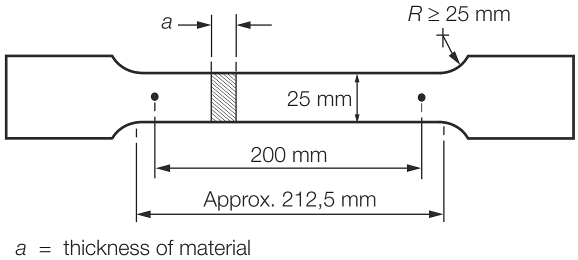


Figure 2.2.4 Test specimen dimensions for plates, strip and sections - II

2.1.7 As an alternative to *Ch 2, 2.1 Dimensions of test specimens 2.1.6*, test specimens with a width of other than 25 mm may be used subject to any requirements for minimum cross-sectional area given in subsequent Chapters of these Rules. A ratio of width/thickness of 8:1 should not be exceeded.

2.1.8 For pipes and tubes, the test specimens may consist of a suitable length tested in full cross-section with the ends plugged. The gauge length is to be $5,65\sqrt{S_o}$ or 50 mm, and the length of the test specimen between the grips or plugs, whichever is the smaller, is to be not less than the gauge length plus *D*, where *D* is the external diameter. Alternatively, test specimens may be prepared from strips cut longitudinally and machined to the dimensions shown in *Figure 2.2.5 Test specimen dimensions for pipes and tubes - I* or *Figure 2.2.6 Test specimen dimensions for pipes and tubes - II*. The parallel test length is not to be flattened, but the enlarged ends may be flattened for gripping in the testing machine. The cross-sectional area of this type of test specimen is to be calculated from:

$$S_o = ab$$

where

S_o = cross-sectional area

a = average radial thickness

b = average width

Test specimens of circular cross-section may also be used provided that the wall thickness is sufficient to allow the machining of such specimens to the dimensions shown in *Figure 2.2.1 Test specimen dimensions for forgings and castings - I*, with their axes located at the mid-wall thickness.

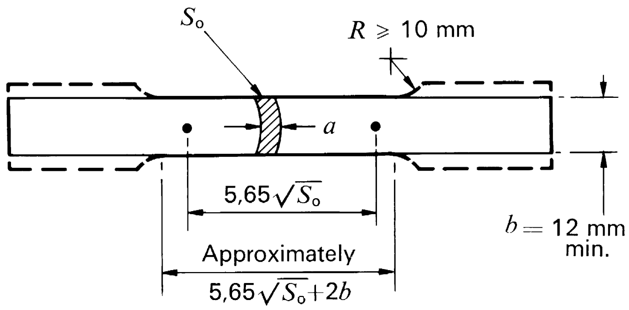


Figure 2.2.5 Test specimen dimensions for pipes and tubes - I

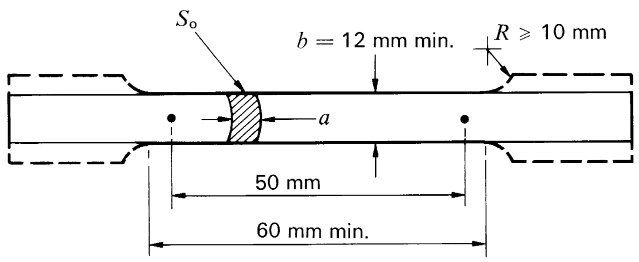


Figure 2.2.6 Test specimen dimensions for pipes and tubes - II

2.1.9 For wire, the test specimen may consist of a suitable length tested in full cross-section. The gauge length is to be 200 mm and the parallel test length 250 mm.

2.1.10 For grey iron castings, the test specimens are to be machined to the dimensions shown in *Figure 2.2.7 Test specimen dimensions for grey iron castings - I* or *Figure 2.2.8 Test specimen dimensions for grey iron castings - II*.

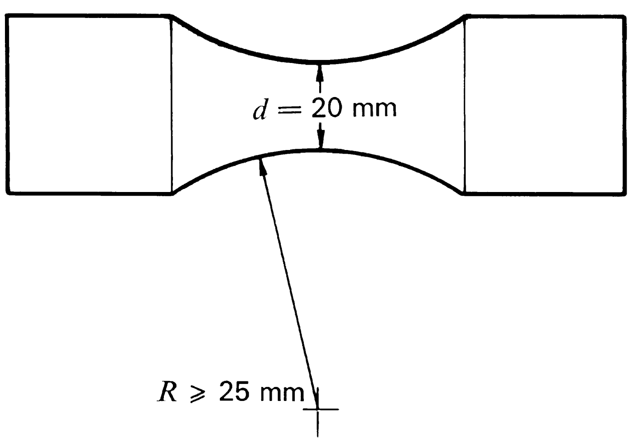


Figure 2.2.7 Test specimen dimensions for grey iron castings - I

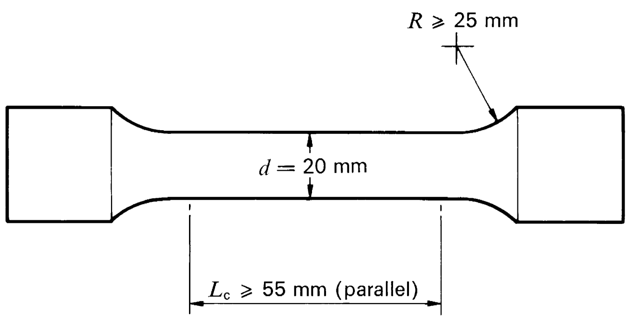


Figure 2.2.8 Test specimen dimensions for grey iron castings - II

2.1.11 For aluminium alloy plates and sections of thickness, a, less than or equal to 12,5 mm; the dimensions of rectangular cross-sectioned test specimens are to be as shown in *Figure 2.2.3 Test specimen dimensions for plates, strip and sections - I and aluminum alloys*. The rectangular cross-sectioned test specimen surfaces should remain as rolled/extruded. Where the thickness, a, is greater than 12,5 mm the test specimens are to be or round type as shown in *Figure 2.2.2 Test specimen dimensions for forgings and castings - II and aluminum alloys*.

2.1.12 Deposited weld metal tensile test specimens are to be machined to the dimensions shown in *Figure 2.2.9 Test specimen for deposited weld metal tensile*, and may be heated to a temperature not exceeding 250°C for a period not exceeding 16 hours for hydrogen removal, prior to testing.

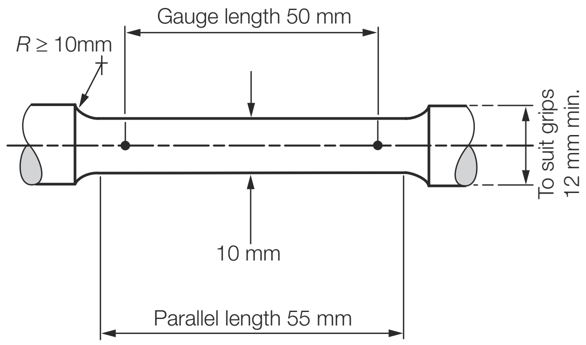


Figure 2.2.9 Test specimen for deposited weld metal tensile

2.1.13 Butt weld tensile test specimens are to be machined to the dimensions shown in *Figure 2.2.10 Test specimen for butt weld*. For thicknesses of more than 2 mm, the test width is to be 25 mm. For thicknesses less than 2 mm, the test width is to be reduced to 12 mm. The upper and lower surfaces of the weld are to be filed, ground or machined flush with the surface of the plate.

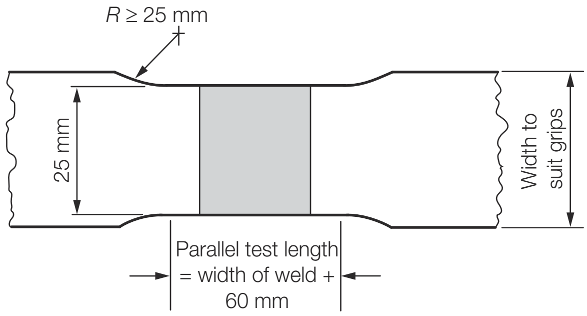


Figure 2.2.10 Test specimen for butt weld

2.1.14 Through thickness tensile test specimens may be, at the option of the steelmaker, either plain test specimens, or test specimens with welded extensions, in accordance with a Recognised Standard.

The extension pieces are to be of steel with a tensile strength exceeding that of the plate to be tested and may be attached to the plate surfaces by manual, resistance or friction welding carried out in such a way as to ensure a minimal heat affected zone.

2.1.15 Tolerances on tensile specimen dimensions are to be in accordance with ISO 6892-1 or another Recognised Standard as appropriate.

2.2 Definition of yield stress for steel

2.2.1 The yield phenomenon is not exhibited by all the steels detailed in these Rules but, except for austenitic and duplex stainless steels, the term `yield stress' is used throughout when requirements are specified for acceptance testing at ambient temperature. For the purposes of the Rules, the terms `yield stress' and `yield strength' are to be regarded as synonymous.

2.2.2 Where reference is made to `yield stress' in the requirements for carbon, carbon-manganese and alloy steel products and in the requirements for the approval of welding consumables, either the upper yield stress or, where this is not clearly exhibited, the 0,2 per cent proof stress or the 0,5 per cent proof stress under load is to be determined. In cases of dispute, the 0,2 per cent proof stress is to be determined.

2.2.3 For austenitic and duplex stainless steel products and welding consumables, both the 0,2 and the 1,0 per cent proof stresses are to be determined.

2.3 Procedure for testing at ambient temperature

2.3.1 Except as provided in *Ch 2, 2.3 Procedure for testing at ambient temperature 2.3.5*, the elastic stress rate for the determination of the upper yield for steels and copper alloys is to be between 6 and 60 N/mm^2 per second and between 2 and 20 N/mm^2 per second for aluminium. After reaching the yield or proof load, the straining rate may be increased to a maximum of 0,008s^{-1} for the determination of the tensile strength.

2.3.2 For steel, the upper yield stress is to be calculated from:

(a) the value of stress measured at the commencement of plastic deformation, or
(b) on a load/extension diagram using the value of stress measured at the first peak obtained during yielding even when the peak is equal to or less than any subsequent peaks observed during plastic deformation at yield.

2.3.3 When a well defined yield point cannot be obtained, the 0,2 or 1,0 per cent proof stress (non-proportional elongation) is to be determined from an accurate load/extension diagram by drawing a line parallel to the straight elastic portion and a distance from it where the amount represents 0,2 or 1,0 per cent of the extensometer gauge length. The point of intersection of this line with the plastic portion of the diagram represents the proof load, from which the 0,2 or 1,0 per cent proof stress can be calculated.

2.3.4 For stainless steels the 1,0 per cent proof stress and/or 0,2 per cent proof stress is specified as required by the relevant Chapters in these Rules.

2.3.5 For the determination of the tensile strength of flake graphite cast iron, the stress rate is not to exceed 10 N/mm^2 per second.

2.4 Equivalent elongations

2.4.1 When a gauge length other than $5,65\sqrt{S_0}$ is used, the equivalent percentage elongation value is to be calculated using the following formula:

$$A = \frac{A_R}{2}\left(\frac{L_0}{\sqrt{S_0}}\right)0,40$$

where

A_R = actual measured percentage elongation of test specimen

S_0 = actual cross-sectional area of test specimen

L_0 = actual gauge length of test piece

A = equivalent percentage elongation for a test specimen with a gauge length of $5,65\sqrt{S_0}$

2.4.2 Alternatively, where a number of test specimens of similar material and dimensions are involved, the actual percentage elongation values may be recorded, provided that the equivalent specified minimum elongation value appropriate for the test specimen dimensions is calculated from the formula in *Ch 2, 2.4 Equivalent elongations 2.4.1* and is recorded on the test certificate.

2.4.3 For proportional test specimens having a gauge length other than $5,65\sqrt{S_0}$, the equivalent elongation may be calculated using the following factors (*d* is the diameter of the test specimen):

Actual gauge length	Factor for equivalent elongation on $5,65\sqrt{S_0}$
$4\sqrt{S_0}$	× 0,870
$8,16\sqrt{S_0}$	× 1,158
$11,3\sqrt{S_0}$	× 1,317
4*d*	× 0,916
8*d*	× 1,207

2.4.4 For non-proportional test specimens with gauge lengths of 50 mm and 200 mm, the equivalent elongation values tabulated in ISO 2566 are to apply.

2.4.5 The above conversions are reliable only for carbon, carbon-manganese and low alloy steels with a tensile strength not exceeding 700 N/mm^2 in the hot rolled, annealed, normalised, or normalised and tempered condition.

2.4.6 For alloy steels in the quenched and tempered condition, the following conversions may be used for proportional test specimens with a gauge length of $4\sqrt{S_0}$:

Actual percentage elongation on $4\sqrt{S_0}$	Equivalent elongation on 5,65 $\sqrt{S_0}$
22	17
20	15
18	13
17	12
16	12
15	11
14	10
12	8

10	7
8	5

2.4.7 Any proposals to use conversion factors for equivalent elongation values for the following materials are to be agreed with the Surveyors:

(a) Carbon, carbon-manganese and alloy steels in the normalised or normalised and tempered condition with a tensile strength exceeding 700 N/mm^2.
(b) Cold-worked steels.
(c) Austenitic stainless steels.
(d) Non-ferrous alloys.

2.5 Procedure for testing at elevated temperatures

2.5.1 Tensile testing at elevated temperatures is to be carried out according to ISO 6892-2 Method B or an equivalent National Standard.

■ *Section 3*
Impact tests

3.1 Dimensions of test specimens

3.1.1 Impact tests are to be of the Charpy V-notch type. The test specimens are to be machined to the dimensions and tolerances given in *Table 2.3.1 Dimensions and tolerances for Charpy V-notch impact test specimens* and are to be carefully checked for dimensional accuracy.

3.1.2 For material under 10 mm in thickness, the largest possible size of standard subsidiary Charpy V-notch test specimen is to be prepared with the notch cut on the narrow face. Generally, impact tests are not required when the thickness of the material is less than 6 mm.

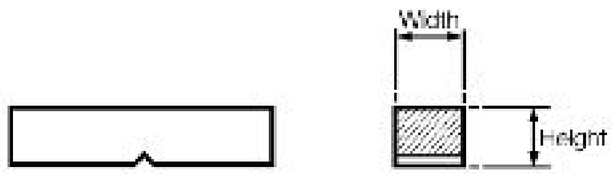
3.2 Testing procedures

3.2.1 All impact tests are to be carried out on Charpy machines approved by Lloyd's Register (hereinafter referred as LR) and having a striking energy of not less than 150 J.

Table 2.3.1 Dimensions and tolerances for Charpy V-notch impact test specimens

Dimension		Nominal	Tolerance
Length, in mm		55	±0,60
Height, in mm, *see* Note 1		10	±0,075
Width , in mm, *see* Note 1			
	- standard specimen	10	±0,11
	- standard subsidiary specimen	7,5	±0,11
	- standard subsidiary specimen	5	±0,06
Angle of notch		45°	±2°
Height below notch, in mm		8	±0,075
Root radius, mm		0,25	±0,025
Distance of plane of symmetry of notch from ends of test piece, in mm, *see* Note 1		27,5	±0,42 *see* Note 2

Angle between plane of symmetry of notch and longitudinal axis of test piece	90°	±2°
Angle between adjacent longitudinal faces of test piece	90°	±2°



Note 1 The test piece is to have a surface roughness better than Ra 5 µm except for the ends.

Note 2 For machines with automatic positioning of the test piece the tolerance is to be taken as ±0,165 mm.

3.2.2 Charpy V-notch impact tests may be carried out at ambient or lower temperatures in accordance with the specific requirements given in subsequent Chapters of these Rules. Where the test temperature is other than ambient, the temperature of the test specimen is to be controlled to within ±2°C for sufficient time to ensure uniformity throughout the cross-section of the test specimen, and suitable precautions are to be taken to prevent any significant change in temperature during the actual test. In cases of dispute, ambient temperature is to be considered as 18°C to 25°C.

3.2.3 For acceptance, the average energy value for a set of three impact tests must be equal to or greater than the appropriate specified minimum average value. Additionally, only one individual value may be less than the required average value but not less than 70 per cent of this average value.

3.2.4 Where standard subsidiary Charpy V-notch test specimens are necessary, the minimum energy values required are to be reduced as follows:

- Specimen 10 x 7,5 mm: 5/6 of tabulated energy.
- Specimen 10 x 5 mm: 2/3 of tabulated energy.

3.2.5 When reporting results, the specimen dimensions and the units used for expressing the energy absorbed (Joules) and the testing temperature are to be clearly stated.

■ *Section 4*
Ductility tests for pipes and tubes

4.1 Bend tests

4.1.1 The test specimens are to be cut as circumferential strips of full wall thickness and with a width of not less than 40 mm. For thick walled pipes, the thickness of the test specimens may be reduced to 20 mm by machining. The edges of the specimens may be rounded to a radius of 1,6 mm.

4.1.2 Testing is to be carried out at ambient temperature, and the specimens are to be doubled over a former whose diameter is to be in accordance with the specific requirements for the material. For submerged arc welded tube the test piece is to be bent with the root of the weld in tension. For other tubes, the test piece is to be bent in the original direction of curvature. In all cases, the welds are to be in the middle of the test specimen. The test is considered to be satisfactory if, after bending, the specimens are free from cracks and laminations. Small cracks at the edges of the test specimens are to be disregarded.

4.2 Flattening tests

4.2.1 Ring test specimens are to be cut with the ends perpendicular to the axis of the pipe or tube. The length of the specimen is to be equal to 1,5 times the external diameter of the pipe or tube, but is to be not less than 10 mm or greater than 100 mm. Alternatively, the length of the test specimen may be 40 mm irrespective of the external diameter.

4.2.2 Testing is to be carried out at ambient temperature and is to consist of flattening the specimens in a direction perpendicular to the longitudinal axis of the pipe. Flattening is to be carried out between two plain parallel and rigid platens which

extend over both the full length and the width after flattening of the test specimen. Flattening is to be continued until the distance between the platens, measured under load, is not greater than the value given by the formula:

$$H = \frac{t(1+C)}{C+\frac{t}{D}}$$

where

H = distance between plates, in mm

t = specified thickness of the pipe, in mm

D = specified outside diameter, in mm

C = a constant dependent on the steel type and detailed in the specific requirements

After flattening, the specimens are to be free from cracks or other flaws. Small cracks at the ends of the test specimens may be disregarded.

4.2.3 For welded pipes or tubes, the weld is to be placed at 90° to the direction of flattening.

4.3 Drift expanding tests

4.3.1 The test specimens are to be cut with the ends perpendicular to the axis of the tube. The edges of the end to be tested may be rounded by filing.

4.3.2 For metallic tubes, the length of the specimen is to be at least 1,5 times the external diameter of the tube except when a mandrel with an included angle of 30° is used, in which case the length of the specimen is to be twice the external diameter of the tube. In all cases the length of section remaining cylindrical after test is not be less than 0,5 times the external diameter.

4.3.3 Testing is to be carried out at ambient temperature and is to consist of expanding the end of the tube symmetrically by means of a hardened conical steel mandrel having a total included angle of 30°, 45° or 60°, *see Figure 2.4.1 Drift expanding test*. The mandrel is to be forced into the test specimen at a rate not exceeding 50 mm/min until the percentage increase in the outside diameter of the end of the test specimen is not less than the value given in the specific requirements for boiler and superheater tubes, *see Ch 6 Steel Pipes and Tubes*. The mandrel is to be lubricated, but there is to be no rotation of the tube or mandrel during the test. The expanded portion of the tube is to be free from cracks or other flaws.

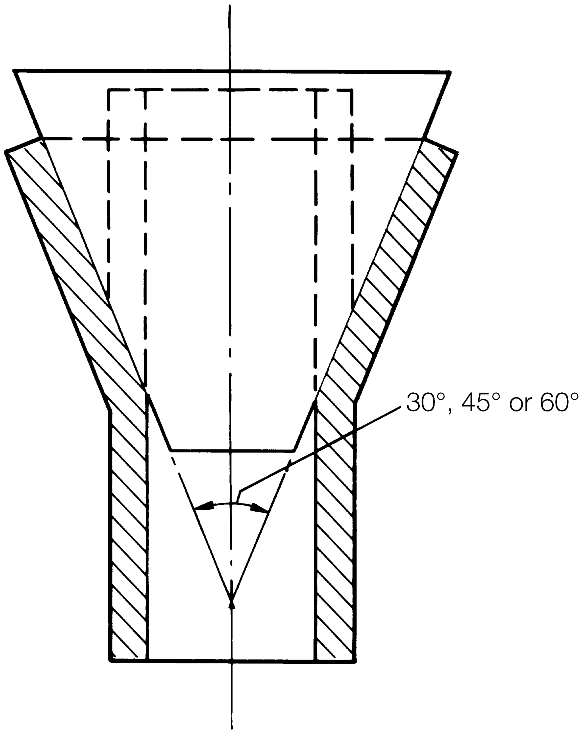


Figure 2.4.1 Drift expanding test

4.4 Flanging tests

4.4.1 The test specimens are to be cut with the ends perpendicular to the axis of the tube. The length of the specimens is to be at least equal to the external diameter of the tube and such that after testing the portion that remains cylindrical is not less than half the external diameter. The edges of the end to be tested may be rounded by filing.

4.4.2 Testing is to be carried out at ambient temperature and is to consist of flanging the end of the tube symmetrically by means of hardened conical steel mandrels. The rate of flanging is not to exceed 50 mm/min.

4.4.3 The first stage of flanging is to be carried out with a conical angled mandrel having an included angle of approximately 90°, *see Figure 2.4.2 Flanging test*. The completion of the test is achieved with a second forming tool as shown in *Figure 2.4.2 Flanging test*. The mandrels are to be lubricated and there is to be no rotation of the tube or mandrels during the test. The test is to continue until the drifted portion has formed a flange perpendicular to the axis of the test specimens. The percentage increase in the external diameter of the end of the specimens is to be not less than the value given in the specific requirements for boiler and superheater tubes, *see Ch 6 Steel Pipes and Tubes*. The cylindrical and flanged portion of the tube is to be free from cracks or other flaws.

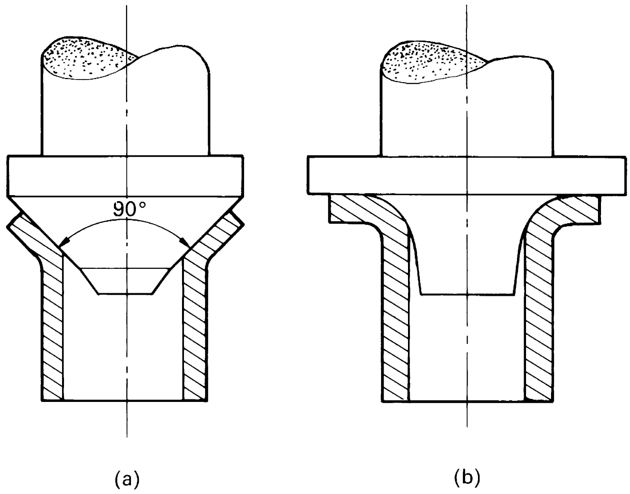


Figure 2.4.2 Flanging test

■ Section 5
Embrittlement tests

5.1 Temper embrittlement tests

5.1.1 The test material is to be heat treated in accordance with the specification except that after tempering:

(a) half the material is to be water quenched;

(b) the other half is to be cooled from the tempering temperature to 300°C at a rate not exceeding 10°C per minute.

5.1.2 Impact tests in accordance with *Ch 2, 3 Impact tests* are to be made on the material in each condition at temperatures over a range wide enough to establish the upper and lower shelf energies and temperatures, tests being made at no less than three intermediate temperatures.

5.1.3 A set of three specimens is to be tested at each temperature. The results are to be plotted separately for each condition, in the form illustrated in *Figure 2.5.1 Idealized transition curve*. In addition, the test temperatures, proportions of crystallinity and absorbed energies for all the specimens tested are to be reported.

5.1.4 The transition temperature for each condition is to be taken as the mid-temperature of the fracture transition zone. The difference between the two transition temperatures is to be reported.

5.2 Strain age embrittlement tests

5.2.1 The test material is to be heat treated in accordance with the specification and then subjected to five per cent strain. Half of the test material is then to be heated to 250°C and held for one hour.

5.2.2 Impact tests in accordance with *Ch 2, 5.1 Temper embrittlement tests 5.1.2* are to be made in both the strained and unstrained conditions.

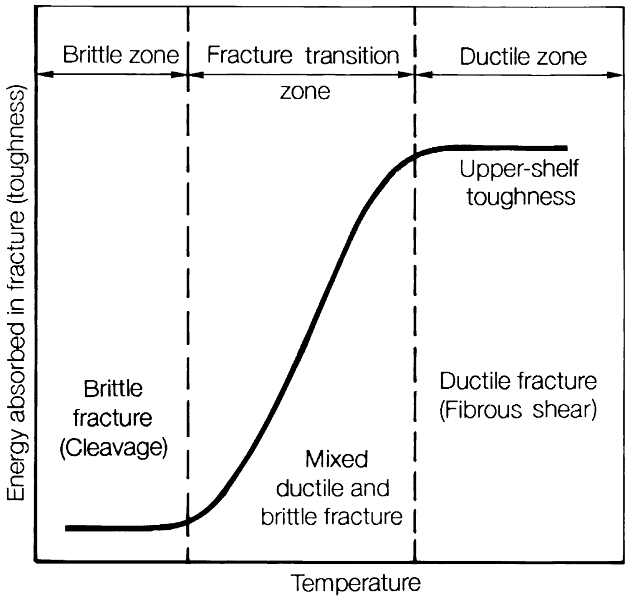


Figure 2.5.1 Idealized transition curve

5.2.3 The tests are to comply with *Ch 2, 5.1 Temper embrittlement tests 5.1.3*.

5.2.4 The test results are treated in accordance with *Ch 2, 5.1 Temper embrittlement tests 5.1.4*.

5.3 Hydrogen embrittlement tests

5.3.1 Two specimens are to be tested. The specimens are to be of a diameter of 20 mm. Where this is not practicable a diameter of 14 mm may be accepted.

5.3.2 One specimen is to be tested within a maximum of 3 hours after machining. Where the specimen diameter is 14 mm, the time limit is 1,5 hours. Alternatively, the specimen may be cooled to –60°C immediately after machining and kept at that temperature for a maximum period of 5 days before being tested.

5.3.3 The other specimen is to be tested after baking at 250°C for 4 hours. Where the specimen diameter is 14 mm the baking time is to be 2 hours.

5.3.4 A strain rate not exceeding 0,0003s^{-1} is to be used during the entire test, until fracture occurs.

5.3.5 Tensile strength, elongation and reduction of area are to be reported.

5.3.6 The ratio Z_1/Z_2 is to be reported, where Z_1 is the reduction in area without baking and Z_2 the reduction in area after baking.

■ *Section 6*
Crack tip opening displacement tests

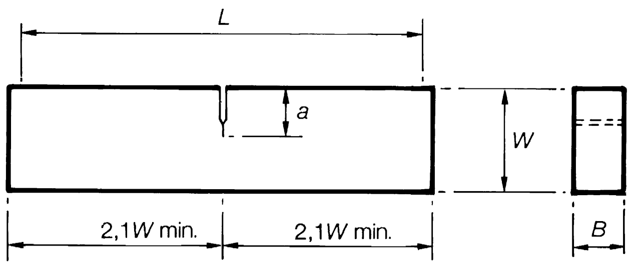
6.1 Dimensions of test specimens

6.1.1 Unless agreed otherwise, tests are to be made on specimens of the full section thickness and which conform to a nationally agreed standard.

6.1.2 Normally the specimens are to be rectangular with the main dimensions as indicated in *Figure 2.6.1 Outline dimensions of the preferred specimen* and are to be tested in three point bending.

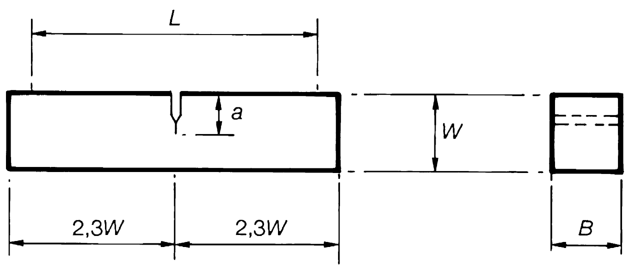
6.1.3 A subsidiary specimen as in *Figure 2.6.2 Outline dimensions of the subsidiary specimen* may be used by agreement.

6.1.4 In each case the notch is to be positioned at the centre of the loading span; its root radius is not to exceed 0,10 mm. The notch is to be extended by the generation of a fatigue crack to give an effective crack length of the dimension *a*. For this purpose, the fatigue stress ratio, R_1, is to be within the range 0 to 0,1 and the fatigue intensity is not to exceed $0{,}63\sigma_\gamma B^{1/2}$ where σ_γ is the 0,2 per cent proof stress at the test temperature.



B = thickness
W = width = 2*B*
a = effective crack length = 0,45*W* to 0,55*W*
L = loading span = 4*W*

Figure 2.6.1 Outline dimensions of the preferred specimen



B = thickness
W = width = *B*
a = effective crack length (to be agreed between the purchaser and manufacturer)
L = loading span = 4*W*

Figure 2.6.2 Outline dimensions of the subsidiary specimen

6.2 Test equipment

6.2.1 Whenever possible, tests are to be made using machines operating under displacement control. The type of control is to be recorded.

6.2.2 The test equipment is to be calibrated annually.

6.2.3 The crack opening displacement gauge is to have an accuracy of at least one per cent. It is to be calibrated at least once every day of testing and at intervals of no more than 10 tests. It should be demonstrated that the calibration is satisfactory for the test conditions.

6.3 Testing procedures

6.3.1 Tests are to be made in a recognised test house in accordance with a nationally accepted standard.

6.3.2 Unless otherwise agreed, all tests on unwelded wrought material are to be made on specimens taken transverse to the principal working direction and are to be through thickness notched.

6.3.3 Where tests are made on weld material, the fatigue crack should be arranged to sample the maximum amount of unrefined weld metal.

6.3.4 Where tests are made on the Heat Affected Zone (H.A.Z.) of a weld, a K or single bevel weld preparation is recommended. The region of lowest fracture toughness in the Heat Affected Zone should be identified for the particular steel and weld procedure by means of preliminary tests. The fatigue crack is to be accurately positioned to sample as high a proportion of this critical region as possible and after testing has been completed, the specimen is to be sectioned to check that this has been achieved. Sufficient tests should be made to ensure that the critical region has been sampled in at least three specimens.

6.3.5 At least three valid tests are to be made for each material condition. Invalid tests are to be disregarded and the tests repeated.

6.3.6 Local pre-compression of the test specimen ahead of the notch is acceptable in order to provide an acceptably even fatigue crack front.

6.3.7 The temperature of the test piece is to be measured to within ±2°C over the range minus 196°C to +200°C and to within ±5°C outside this range. The temperature should be measured at a point on the specimen not farther than 2 mm away from the crack tip.

6.4 Validity requirements

6.4.1 The test is to be regarded as invalid if:

(a) the fatigue crack front is not in a single plane;
(b) any part of the fatigue crack surface lies in a plane whose angle with the plane of the notch exceeds 10°;
(c) the length of any part of the fatigue crack is less than 0,025W or 1,25 mm, whichever is the greater;
(d) the difference between the maximum and minimum lengths of the fatigue crack exceeds 0,1W;
(e) the difference between any two of the lengths of the fatigue crack at 0,25B, 0,5B and 0,75B exceeds 0,05W.

6.4.2 In addition, for tests on welds and Heat Affected Zones (H.A.Z.), the following criteria are to be complied with:

(a) Weld metal. The fatigue crack front shall not extend outside the weld metal deposit and 80 per cent should be within 2 mm of the fusion line.
(b) Grain coarsened H.A.Z.. The fatigue crack should be within 0,5 mm of the fusion line and should sample all of the grain coarsened H.A.Z. present. However, if fusion line irregularities prevent this, a sample including as much grain coarsened H.A.Z. as possible may be accepted.
(c) Subcritical/intercritical H.A.Z. boundary. The fatigue crack is to sample the boundary between the subcritical and intercritical regions of the H.A.Z. However, if fusion line irregularities prevent this, a sample including as much relevant microstructure as possible may be accepted.

6.5 Test reports

6.5.1 The test report is to include:

(a) details of the material, its condition and size;
(b) the thickness and width of the test specimen;
(c) the fatigue pre-cracking conditions;
(d) the test temperature and environment;
(e) the test machine control system and rate of change of displacement or load;
(f) crack length measurements;
(g) force/displacement records, preferably in the form of an autographic record;
(h) the critical crack opening displacement;
(i) a photograph of the fracture;
(j) any observation on the fracture surface.

Section 7
Bend tests

7.1 Dimensions of test specimens

7.1.1 Flat bend test specimens are to be of rectangular cross-section with dimensions as defined in *Figure 2.7.1 Bend test specimen*.

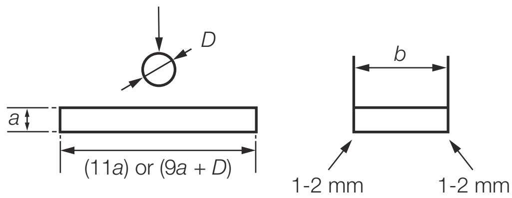


Figure 2.7.1 Bend test specimen

7.1.2 For plates, sections and strip the dimensions shall be full thickness and width 30 mm. Where the rolled thickness exceeds 25 mm the compression face may be reduced to 25 mm.

7.1.3 For forgings, castings and semi-finished products the thickness shall be 20 mm and width 25 mm.

7.1.4 Butt weld face and root bend test specimens are to be 30 mm in width and of the full plate thickness. Where the thickness exceeds 12mm, two side bend test specimens may be tested in place of the face and root specimens specified. The side bend specimens should be 10 mm minimum thickness. The upper and lower surfaces of the weld are to be filed, ground or machined flush with the surface of the plate.

7.1.5 The edges on the tension side of bend samples are to be rounded to a radius of 1 to 2 mm.

7.2 Testing procedures

7.2.1 The bend sample is plastically deformed by plunging a mandrel between two fixed points as shown in *Figure 2.7.2 Bend test*.

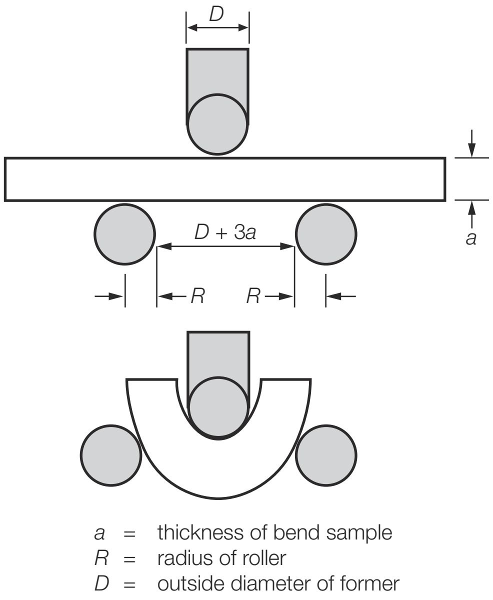


Figure 2.7.2 Bend test

7.2.2 For aluminium welds a guided bend is required to ensure even deformation as shown in *Figure 2.7.3 Guide bend test for aluminium*.

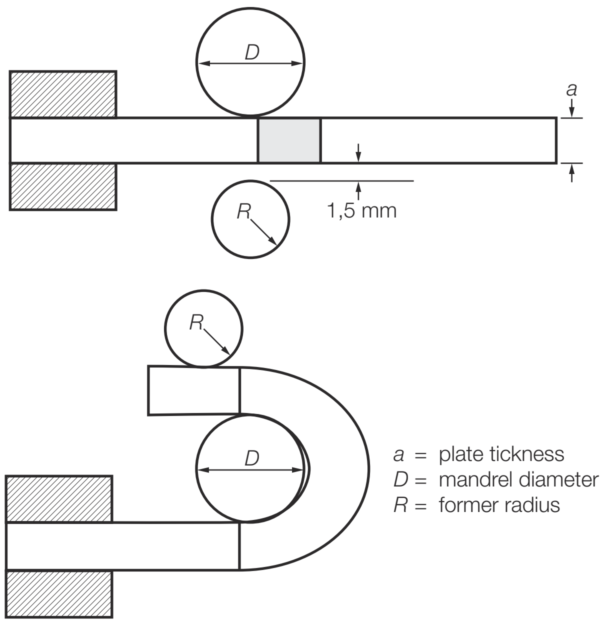


Figure 2.7.3 Guide bend test for aluminium

7.2.3 Bend tests are to be conducted at ambient temperature at the highest convenient rate of bending (but not impact).

Section 8
Hardness testing

8.1 Dimensions of test specimens

8.1.1 Test pieces must be held rigidly in relation to the indenter and located such that the surface to be tested is at right angles to the axis of the indenter.

8.1.2 The surface finish of the test piece is to be such as to be able to measure the indent accurately.

8.2 Testing procedure

8.2.1 Hardness testing is to be carried out according to ISO 6506-1, ISO 6507-1 or equivalent for the type of hardness test.

Section 9
Corrosion tests

9.1 Intergranular corrosion test

9.1.1 For all products other than pipes, the material for the test specimens is to be taken adjacent to that for the tensile test and is to be machined to suitable dimensions for either a round or rectangular section bend test. The diameter or thickness is to be not more than 12 mm, and the total surface area is to be between 1500 mm^2 and 3500 m^2.

9.1.2 For pipes with an outside diameter not exceeding 40 mm, the test specimens are to consist of a full cross-section. For larger pipes, the test specimens are to be cut as circumferential strips of full wall thickness and having a width of not less than 12,5 mm. In both cases the total surface area is to be between 1500 mm^2 and 3500 m^2.

9.1.3 Specimens are to be heated to a temperature of 700 ± 10 ºC for 30 minutes, followed by rapid cooling in water. They are then to be placed on a bed of copper turnings (50 g per litre of test solution) and immersed for 15 to 24 hours in a boiling solution of the following composition:

- 100 g of hydrated copper sulphate granules ($CuSO_4$. $5H_2O$)
- 184 g (100 ml) sulphuric acid (density 1,84 g/ml) added dropwise to distilled water to make 1 litre of solution.

Precautions are to be taken during boiling to prevent concentration of the solution by evaporation.

9.1.4 After immersion, the full cross-section test specimens from pipes are to be subjected to a flattening test in accordance with *Ch 2, 4.2 Flattening tests*. All other test specimens are to be bent, at ambient temperature, through 90º over a former with a diameter equal to twice the diameter or thickness of the test specimen.

9.1.5 After flattening or bending, the test specimens are to be free from cracks on the outer, convex surface.

9.2 Pitting corrosion test

9.2.1 The material for the test specimens is to be taken adjacent to that for the tensile test and is to be machined to a round or rectangular test piece of thickness approximately 6 mm with total surface area between 1500 mm^2 and 3500 mm^2. Any deformed material at the edges is to be removed.

9.2.2 All surfaces of the specimen are to be polished to a uniform finish using 120 grit abrasive paper. Sharp edges are to be removed and, after polishing, the specimen should be thoroughly washed and dried.

9.2.3 The dimensions of the surface are to be measured in order to calculate the exposed area.

9.2.4 The specimen is to be weighed to an accuracy of 0,001g or greater.

9.2.5 For the corrosive media 100g of reagent grade ferric chloride, $FeCl_3.6H_2O$, is dissolved in 900ml of de-ionised water and filtered to remove insoluble particles.

9.2.6 At least 250ml of ferric chloride solution is to be added to a glass test container. The container is to be placed in a water bath and allowed to reach the required test temperature. The bath temperature shall be monitored and recorded in order to ensure that the temperature is satisfactorily maintained throughout the test. Once the test temperature has been achieved, the test piece is to be placed in a glass cradle and lowered into the solution.

9.2.7 A glass cover is to be placed over the vessel to allow the test piece to remain undisturbed throughout the duration of the test. The standard duration of the test is 72 hours.

9.2.8 At the end of the test, the specimen is to be removed from the solution. It shall be rinsed with water, scrubbed with a nylon bristle brush under running water to remove corrosion products, and then dried.

9.2.9 The surface of the specimen is to be thoroughly inspected to a magnification of x20 and the specimen is weighed to an accuracy of 0,001 g or better.

9.2.10 The results obtained shall be recorded and these shall include the weight loss expressed as g/m^2 and a description of the surface appearance, noting any evidence of pitting corrosion.

9.2.11 Unless otherwise agreed, the acceptance criteria for the test are that there shall be no evidence of pitting at x20 magnification and that the maximum weight loss shall be 0,8 g/m^2.

Contents

■ *Section 1*
General requirements

1.1 Scope

1.1.1 This Section gives the general requirements for hot rolled plates and sections intended for use in the construction of ships, other marine structures, machinery, boilers and pressure vessels.

1.1.2 This Chapter is not applicable to hot rolled bars intended for the manufacture of bolts, plain shafts, etc. by machining operations only. Where used for this purpose, hot rolled bars are to comply with the requirements of *Ch 5 Steel Forgings*.

1.1.3 Plate and strip which is hot coiled after rolling and subsequently uncoiled, cold flattened and cut to the required dimensions are also subject to the appropriate requirements of this Chapter.

1.1.4 Plates, strip, sections and bars are to be manufactured and tested in accordance with the requirements of *Ch 1 General Requirements* and *Ch 2 Testing Procedures for Metallic Materials*, the general requirements of this Section and the appropriate specific requirements given in Sections *Ch 3, 2 Normal strength steels for ship and other structural applications*.

1.1.5 As an alternative to *Ch 3, 1.1 Scope 1.1.4*, materials which comply with National or proprietary specifications may be accepted, provided that these specifications give equivalence to the requirements of this Chapter or are approved for a specific application. Particular attention is to be taken of the minimum required under thickness tolerance, *see Ch 3, 1.6 Dimensional tolerances*. Generally, survey and certification of such materials are to be carried out in accordance with the requirements of *Ch 1 General Requirements*.

1.1.6 Steels intended for high heat input welding above 50 kJ/cm are to be specially approved. Approval will be indicated on the manufacturer's approval certificate by adding a high heat input welding notation to the grade approved e.g. EH36-W300, indicating approval up to 300 kJ/cm.

1.2 Steel with guaranteed through thickness properties – 'Z' grade steel

1.2.1 When plate material, intended for welded construction, will be subject to significant strains in a direction perpendicular to the rolled surfaces, it is recommended that consideration be given to the use of special plate material with specified through thickness properties, 'Z' grade steel. These strains are usually associated with thermal contraction and restraint during welding, particularly for full penetration 'T'-butt welds, but may also be associated with loads applied in service or during construction. Where these strains are of sufficient magnitude, lamellar tearing may occur. Requirements for 'Z' grade plate material are detailed in *Ch 3, 8 Plates with specified through thickness properties*. It is the responsibility of the fabricator to make provision for the use of this material.

1.2.2 Steels intended to have guaranteed through thickness properties will include the supplementary suffix Z25 or Z35 in the designation, for example: LR DH36 Z35.

1.3 Corrosion resistant steels for cargo oil tanks of crude oil tankers

1.3.1 This sub-Section refers to normal and higher strength steels that have approved enhanced corrosion resistance properties intended for application in the internal cargo oil tanks of crude oil tankers.

1.3.2 The additional approval procedures for these steels include specific corrosion tests, *see Ch 1, 2.2 LR Approval – General* and *Ch 15, 3 Corrosion Resistant Steels* .

1.3.3 Normal and higher strength corrosion resistant steels are to be manufactured, tested and certified in accordance with the applicable requirements detailed in this section, and those of *Ch 3, 2 Normal strength steels for ship and other structural applications* or *Ch 3, 3 Higher strength steels for ship and other structural applications* , as applicable, and the requirements detailed in *Ch 15, 3 Corrosion Resistant Steels* .

1.3.4 Corrosion resistant steels for cargo oil tanks are primarily intended to apply to steel plates, wide flats and sections up to 50 mm thick and to bars up to 50 mm in diameter.

1.3.5 Corrosion resistant steels for cargo oil tanks are to be identified with one of the following supplementary suffixes, RCU, RCB or RCW in the designation, for example, LR DH36 RCB. These suffixes relate to the area of the tank for which approval testing has been obtained:

(a) RCU, for the lower surface of strength deck and surrounding structures, defined as the deckhead with complete internal structure, including brackets connecting to longitudinal and transverse bulkheads. In addition:
   (i) In tanks with ring frame girder construction the underdeck transverse framing is to be protected down to level of the first tripping bracket below the upper faceplate;
   (ii) Longitudinal and transverse bulkheads are to be protected to the uppermost means of access level. The uppermost means of access and its supporting brackets are to be fully protected.
   (iii) On cargo tank bulkheads without an uppermost means of access the protection is to extend to 10 per cent of the tank's height at centreline but need not extend more than 3 m down from the deck.
(b) RCB, for the upper surface of inner bottom plating and surrounding structures, defined as the flat inner bottom and all structure to a height of 0,3 m above inner bottom, is to be protected;
(c) RCW, for both strength deck and inner bottom plating.

1.3.6 Corrosion resistant steels are not to be used in applications other than those specified in *Ch 3, 1.3 Corrosion resistant steels for cargo oil tanks of crude oil tankers 1.3.1*.

1.3.7 The weldability of corrosion resistant steels is similar to conventional normal and higher strength steels. Therefore the welding requirements specified in *Ch 11 Approval of Welding Consumables* are to be adhered with the exception that each corrosion resistant steel is approved with a specified brand of welding consumable and associated welding process.

1.3.8 Each manufacturer's approval certificate for corrosion resistant steels will state the steel grade and area of application designation, specified chemical composition range including additive and/or controlling element percentages to improve corrosion resistance, and brand of welding consumables and welding process used for approval.

1.4 Manufacture

1.4.1 All materials are to be manufactured at works which have been approved by Lloyd's Register for the type and grade of steel which is being supplied and for the relevant steel-making and processing route.

1.4.2 Steel is to be cast in metal ingot moulds or by the continuous casting process. The size of the ingot, billet or slab is to be proportional to the dimensions of the final product such that the reduction ratio is normally to be at least 3 to 1. Sufficient discard is to be taken to ensure soundness in the portion used for further processing.

1.4.3 The cast analysis to be used for certification purposes is to be determined after all alloying additions have been carried out and sufficient time allowed for such an addition to homogenise.

1.4.4 Material may be supplied either as-rolled, normalised, normalising rolled, or thermomechanically controlled rolled. The following definitions apply:

(a) As-rolled (AR) refers to rolling of steel at high temperature followed by air cooling. The rolling and finishing temperatures are typically in the austenite recrystallisation region and above the normalising temperature. The strength and toughness properties of steel produced by this process are generally less than those of steel heat treated after rolling or steel produced by advanced processes.

(b) Normalising (N) refers to an additional heating cycle of rolled steel above the critical temperature, A_{c3}, and in the lower end of the austenite recrystallisation region followed by air cooling. The process improves the mechanical properties of as-rolled steel by refining the grain size.

(c) Normalising rolling (NR), also known as controlled rolling, is a rolling procedure in which the final deformation is carried out in the normalising temperature range, resulting in a material condition generally equivalent to that obtained by normalising.

(d) Thermomechanically controlled rolling (TM) is a procedure which involves the strict control of both the steel temperature and the rolling reduction. Generally a high proportion of the rolling reduction is carried out close to the A_{r3} temperature and may involve the rolling in the dual phase temperature region. Unlike normalising rolling the properties conferred by TM (TMCP) cannot be reproduced by subsequent normalising or other heat treatment. The use of accelerated cooling on completion of TM may also be accepted subject to the special approval by LR.

(e) Accelerated Cooling, (AcC) is a process which aims to improve mechanical properties by controlled cooling with rates higher than air cooling immediately after the final TM operation. Direct quenching is excluded from accelerated cooling. The material properties conferred by TM and AcC cannot be reproduced by subsequent normalising or other austenitising heat treatment.

(f) Quenching and Tempering (QT) is a heat treatment process in which steel is heated to an appropriate temperature above the A_{c3} and then cooled with an appropriate coolant for the purpose of hardening the microstructure, followed by tempering, a process in which the steel is re-heated to an appropriate temperature, not higher than the A_{c1} to restore the toughness properties by improving the microstructure.

1.4.5 Where material is being produced by a normalising rolling or a thermomechanically controlled process (T.M.) an additional program of tests for approval is to be carried out under the supervision of the Surveyors and the results are to be to the satisfaction of LR.

1.4.6 Weldable high strength steels may be supplied in the quenched and tempered condition for other marine structures, *see Ch 3, 10 High strength quenched and tempered steels for welded structures*.

1.5 Quality of materials

1.5.1 Surface and internal imperfections not prejudicial to the proper application of the steel are not, except by special agreement, to be grounds for rejection. Where necessary, suitable methods of non-destructive examination may be used for the detection of harmful surface and internal defects. The extent of this examination, together with an appropriate acceptance standard, is to be agreed between the purchaser, steelmaker and Surveyor and is to be included in the manufacturing specification.

1.6 Dimensional tolerances

1.6.1 The tolerances on thickness of a given product are defined as:

(a) Minus tolerance is the lower limit of the acceptable range below the nominal thickness.

(b) Plus tolerance is the upper limit of the acceptable range above the nominal thickness.

Nominal thickness is defined by the purchaser at the time of enquiry and order.

1.6.2 The average thickness of a product or products is defined as the arithmetic mean of the measurements made in accordance with the requirements in *Ch 3, 1.6 Dimensional tolerances 1.6.11*.

1.6.3 For materials of nominal thickness 5 mm and more intended for hull structural purposes as detailed in *Ch 3, 2 Normal strength steels for ship and other structural applications*, *Ch 3, 3 Higher strength steels for ship and other structural applications* and *Ch 3, 10 High strength quenched and tempered steels for welded structures*, the minus tolerance on thickness of plates, strip and wide flats is 0,3 mm, irrespective of nominal thickness. For wide flats, this applies only where the width is greater than or equal to 600 mm. The average thickness of a product or products is not to be less than the nominal thickness. For thicknesses below 5 mm, the thickness tolerances are to be specially agreed. Plus tolerance is to be in accordance with a National or International standard.

1.6.4 Class C of ISO 7452 may be applied in lieu of *Ch 3, 1.6 Dimensional tolerances 1.6.3*. Where this standard is applied, both the requirements in *Ch 3, 1.6 Dimensional tolerances 1.6.11* and the portion of the footnote of Table B.2 in ISO 7542, that reads; 'Also a minus side of thickness of 0,3 mm is permitted', are not applicable. Additionally, if ISO 7452 is applied, the steel mill is to ensure that the number of measurements and measurement distribution is appropriate to establish that the plates produced are greater than or equal to the specified nominal thickness.

1.6.5 The minus tolerance on bars and sections (except for wide flats with a width ≥ 600 mm) is to be in accordance with the requirements of a recognised National or International Standard.

1.6.6 The Shipbuilder and Owner may agree in individual cases whether they wish to specify a more stringent minus tolerance than that given in this Chapter.

1.6.7 The minus tolerances for plates and wide flats intended for machinery structures are given in *Ch 3, 5 Steels for machinery fabrications*.

1.6.8 For materials intended for applications as detailed in *Ch 3, 4 Steels for boilers and pressure vessels* and *Ch 3, 6 Ferritic steels for low temperature service*, no minus tolerance is permitted in the thickness of plates and strip. The minus tolerances on sections are to comply with the requirements of a recognised National or International Standard.

1.6.9 For the materials detailed in *Ch 3, 7 Austenitic and duplex stainless steels*, the minus tolerance of material intended for use in the construction of cargo tanks is not to exceed 0,3 mm. For other applications, no minus tolerance is permitted in the thickness of plates and strip.

1.6.10 Dimensional tolerances for material detailed in *Ch 3, 9 Bars for welded chain cables* are given in *Table 3.9.3 Dimensional tolerance of bar stock*.

1.6.11 The average thickness and thickness tolerance is to be measured at locations of a product or products as defined below:

(a) An automated method or manual method may be applied to the thickness measurements. The procedure and the records of measurements are to be made available to the Surveyor and copies provided on request.
(b) At least two lines among Line 1, Line 2 or Line 3, as shown in *Figure 3.1.1 Location of thickness measuring points*, are to be selected for the thickness measurements and at least three points on each selected line as shown in *Figure 3.1.1 Location of thickness measuring points* are to be selected for thickness measurement on each piece rolled from a single slab or single ingot. If more than three points are taken on each line, then the number of points shall be equal on each line.
(c) For automated methods, the measuring points at sides are to be located not less than 10 mm but not greater than 300 mm from the transverse or longitudinal edges of the product.
(d) For manual methods, the measuring points at sides are to be located not less than 10 mm but not greater than 100 mm from the transverse or longitudinal edges of the product.
(e) Additional measurements may be requested by the Surveyor.

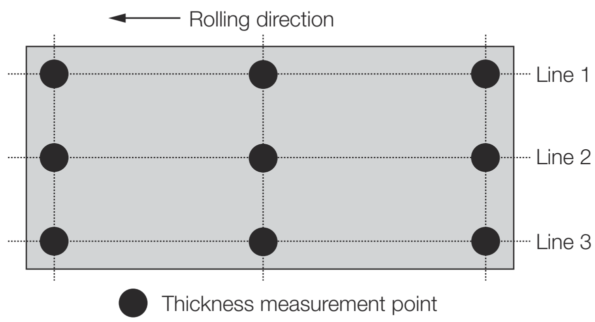


Figure 3.1.1 Location of thickness measuring points

1.6.12 Local surface depressions resulting from imperfections and ground areas resulting from the elimination of defects may be disregarded provided that they are in accordance with the requirements of a recognised National or International Standard.

1.6.13 Tolerances relating to length, width, flatness and plus thickness are to comply with a National or International Standard.

1.6.14 The responsibility for maintaining the required tolerances and making the necessary measurements rests with the manufacturer. Occasional checking by the Surveyor does not absolve the manufacturer from this responsibility.

1.6.15 The Shipbuilder is responsible for the storage and maintenance of product(s) delivered with acceptable surface conditions.

1.7 Heat treatment

1.7.1 Acceptable conditions of supply are specified in subsequent Sections of this Chapter.

1.7.2 The manufacturer is to carry out any heat treatment which may be necessary to prevent hydrogen cracking or to make the material in a safe condition for transit. The Surveyor is to be advised of any heat treatment proposed.

1.7.3 Where material is manufactured using a thermomechanically controlled process consideration must be given to the possibility of consequent reduction in mechanical properties if it is subjected to heating for forming or stress relieving or is welded using a high heat input.

1.8 Test material and mechanical tests

1.8.1 Depending on the type of product, provision is made in subsequent Sections of this Chapter for the testing of individual items or for batch testing. Where the latter is permitted, all materials in a batch presented for acceptance tests are to be of the same product form, (e.g. plates, flats, sections, etc.), from the same cast and in the same condition of supply.

1.8.2 The test samples are to be fully representative of the material and, where appropriate, are not to be cut from the material until heat treatment has been completed. The test specimens are not to be separately heat treated in any way.

1.8.3 The test material is to be taken from the thickest piece in each batch, *see Ch 1, 4.1 General*.

1.8.4 Test material is to be taken from the following positions:

(a) At the square cut end of plates and flats greater than 600 mm wide, approximately one-quarter width from an edge, *see Figure 3.1.2 Position of test material*.
(b) For flats 600 mm or less in width, bulb flats and other solid sections, at approximately one-third of the width from an edge, *see Figure 3.1.2 Position of test material*, *Figure 3.1.2 Position of test material* and *Figure 3.1.2 Position of test material*. Alternatively, in the case of channels, beams or bulb angles, at approximately one-quarter of the width from the centreline of the web, *see Figure 3.1.2 Position of test material*.
(c) For rectangular hollow sections, at approximately the centre of any side, *see Figure 3.1.2 Position of test material*. For circular hollow sections, at any position on the periphery.
(d) For bars intended for purposes as detailed in *Ch 3, 2 Normal strength steels for ship and other structural applications*, *Ch 3, 3 Higher strength steels for ship and other structural applications*, *Ch 3, 5 Steels for machinery fabrications* and *Ch 3, 9 Bars for welded chain cables*, at approximately one-third of the radius or half-diagonal from the outer surface, *see Figure 3.1.2 Position of test material*. For smaller bars, the position of the test material is to be as close as is possible to the above.
(e) For bars intended for the applications detailed in *Ch 3, 4 Steels for boilers and pressure vessels*, *Ch 3, 6 Ferritic steels for low temperature service* and *Ch 3, 7 Austenitic and duplex stainless steels* at approximately 12,5 mm below the surface. For bars up to 25 mm diameter, the test specimens may be machined coaxially.
(f) For plates and flats with thicknesses in excess of 40 mm, full thickness specimens may be prepared, but when instead a machined round specimen is used then the axis is to be located at a position lying one-quarter of the product thickness from the surface as shown in *Figure 3.1.2 Position of test material*.

1.8.5 Tensile test specimens and impact test specimens, where required for the type and grade of product being supplied, are to be prepared from each item or batch of material submitted for acceptance.

1.8.6 Where the finished width of plates and flats is greater than 600 mm, the tensile test specimens are to be cut with their principal axes perpendicular to the final direction of rolling. For all other rolled products, the principal axes are to be parallel to the final direction of rolling.

1.8.7 The tensile test specimens are to be machined to the dimensions detailed in *Ch 2, 2.1 Dimensions of test specimens 2.1.6* and *Ch 2, 2.1 Dimensions of test specimens 2.1.7*.

1.8.8 Impact test specimens are to be cut with their principal axes either parallel (longitudinal test) or perpendicular (transverse test) to the final direction of rolling, as required by subsequent Sections of this Chapter. Where both longitudinal and transverse impact properties are shown for a particular grade, only the longitudinal test is required to be carried out, unless otherwise specified by the purchase order or subsequent Sections of this Chapter. However, for plates and wide flats, by certifying that the product meets the requirements of the Rules, the manufacturer guarantees that the acceptance values will be met if tested in the transverse direction. The Surveyor may request testing in this direction to confirm conformity.

1.8.9 Impact test specimens are to be of the Charpy V-notch type, machined to the dimensions detailed in *Ch 2 Testing Procedures for Metallic Materials*. They are to be taken from a position within 2 mm of one of the rolled surfaces, except that for plates and sections over 40 mm thick, the axes of the test specimens are to be at one-quarter of the thickness from one of the rolled surfaces. For bars and other similar products the axes of the test specimens are to be as specified in *Ch 3, 1.8 Test material and mechanical tests 1.8.4*.

1.8.10 Standard test specimens 10 mm square are to be used, except where the thickness of the material does not allow this size of test specimen to be prepared. In such cases the largest possible size of subsidiary test specimen, in accordance with *Table*

2.3.1 Dimensions and tolerances for Charpy V-notch impact test specimens is to be prepared, with the notch cut on the narrow face. Alternatively, for material of suitable thickness, the rolled surfaces may be retained so that the test specimen width will be the full thickness of the material. In such cases the tolerances for width given in *Table 2.3.1 Dimensions and tolerances for Charpy V-notch impact test specimens* in Chapter 2 are not applicable. The notch is to be cut in a face of the test specimen which was originally perpendicular to the rolled surface. The position of the notch is to be not nearer than 25 mm to a flame-cut or sheared edge.

1.8.11 Impact tests are not required when the nominal material thickness is less than 6 mm.

1.8.12 The test procedures used for all tensile and impact tests are to be in accordance with the requirements of *Ch 2 Testing Procedures for Metallic Materials*.

1.9 Visual and non-destructive examination

1.9.1 Surface inspection and verification of dimensions are the responsibility of the steelmaker and are to be carried out on all material prior to despatch. Acceptance by the Surveyors of material later found to be defective shall not absolve the steelmaker from this responsibility.

1.9.2 With the exception of 'Z' grade plate material (*see Ch 3, 8 Plates with specified through thickness properties*) and bars for offshore mooring cable (*see Ch 3, 9 Bars for welded chain cables*), the non-destructive examination of materials is not required for acceptance purposes, *see also Ch 3, 1.5 Quality of materials 1.5.1*. However, manufacturers are expected to employ suitable methods of non-destructive examination for the general maintenance of quality standards.

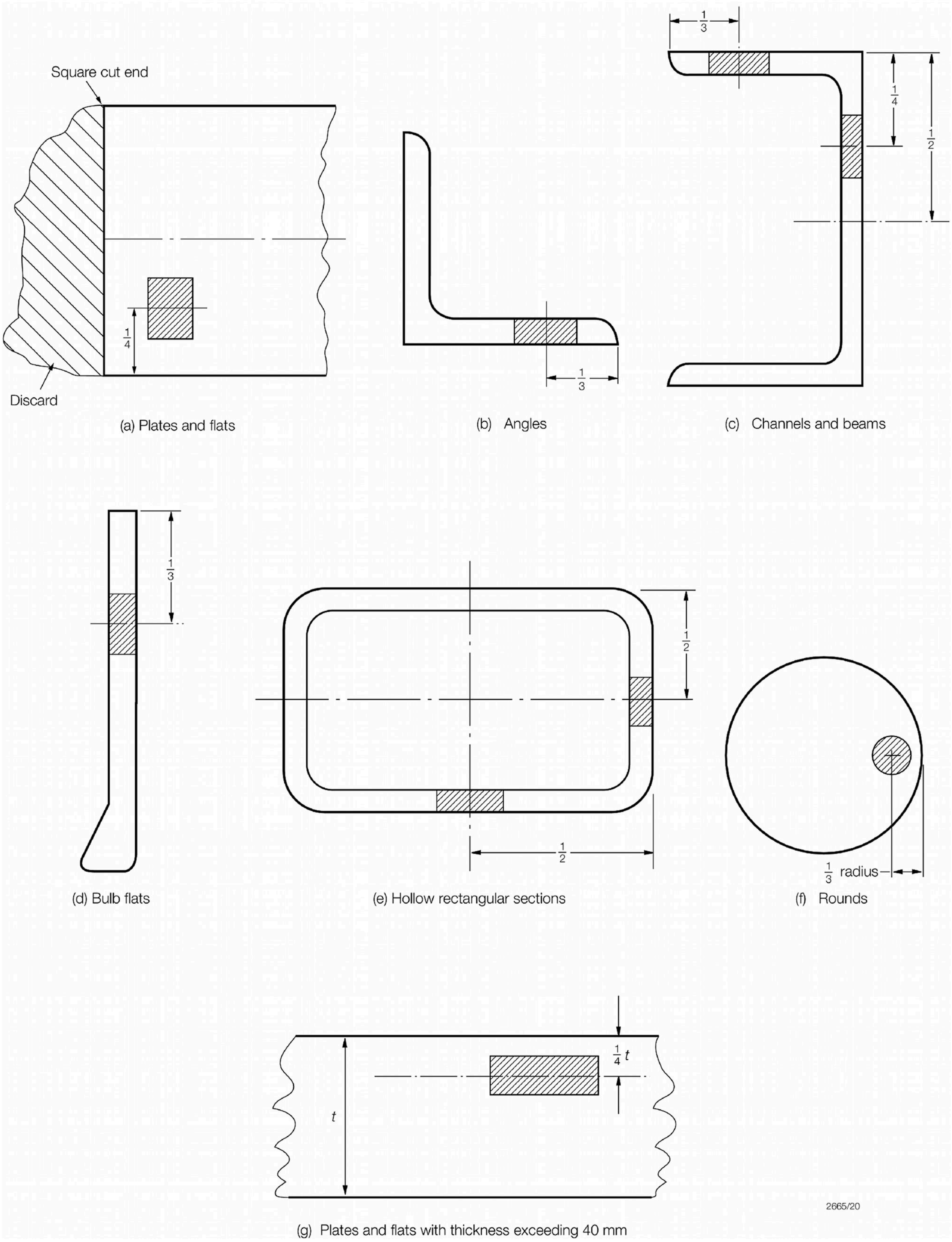


Figure 3.1.2 Position of test material

1.10 Rectification of defects

1.10.1 For materials intended for structural purposes as detailed in *Ch 3, 2 Normal strength steels for ship and other structural applications*, *Ch 3, 3 Higher strength steels for ship and other structural applications* and *Ch 3, 5 Steels for machinery fabrications*, surface defects may be removed by local grinding provided that:

(a) the thickness is in no place reduced to less than 93 per cent of the nominal thickness, but in no case by more than 3 mm,
(b) each single ground area does not exceed 0,25 m^2,
(c) the total area of local grinding does not exceed two per cent of the total surface,
(d) the ground areas have smooth transitions to the surrounding surface.

Where necessary, the entire surface may be ground to a maximum depth as given by the underthickness tolerances of the product. The extent of such rectification is to be agreed in each case with the Surveyors and is to be carried out under their supervision, unless otherwise agreed. They may request that complete removal of the defect is proven by suitable non-destructive examination of the affected area.

1.10.2 Surface defects which cannot be dealt with as in *Ch 3, 1.10 Rectification of defects 1.10.1* may be repaired by chipping or grinding followed by welding, subject to the Surveyor's consent and under his supervision, provided that:

(a) after removal of the defect and before welding, the thickness of the item is in no place reduced by more than 20 per cent,
(b) each single weld does not exceed 0,125 m^2,
(c) the total area of welding does not exceed two per cent of the surface of the side involved,
(d) the distance between any two welds is not less than their average width,
(e) the welds are of reasonable size and made with an excess layer of beads which is then ground smooth to the surface level,
(f) elimination of the defect is proven by suitable non-destructive examination of the affected area,
(g) welding is carried out by an approved procedure and by competent operators using approved electrodes and the repaired area is ground smooth to the correct nominal thickness,
(h) when requested by the Surveyor, the item is normalised or otherwise suitably heat treated after welding and grinding, and
(i) at the discretion of the Surveyor, the repaired area is proven free from defects by suitable non-destructive examination.

1.10.3 For materials intended for applications as detailed in *Ch 3, 4 Steels for boilers and pressure vessels*, *Ch 3, 6 Ferritic steels for low temperature service* and *Ch 3, 7 Austenitic and duplex stainless steels*, surface defects may be removed by grinding in accordance with *Ch 3, 1.10 Rectification of defects 1.10.1*, except that when the thickness is reduced below that given in the approved plans, acceptance will be subject to special consideration. Weld repairs may also be carried out generally in accordance with *Ch 3, 1.10 Rectification of defects 1.10.2*, except that in all cases suitable heat treatment after welding and non-destructive testing of the repaired areas is required. The fabricator is to be advised regarding the position and extent of all repairs.

1.10.4 For plates which have been produced by a T.M. process or by normalising rolling, repair by welding will be approved by the Surveyor only after procedure tests have shown that the mechanical properties have not been impaired.

1.10.5 Cracks, shells, sand patches and sharp edged seams are always considered defects which would impair the end use of the product and which require rejection or repair irrespective of their size and number. The same applies to other imperfections exceeding the acceptable limits.

1.11 Identification of materials

1.11.1 Every finished item is to be clearly marked by the manufacturer in at least one place with LR's brand ”LR” and the following particulars:

(a) The manufacturer's name or trade mark.
(b) The grade of steel. The designations given in subsequent Sections of this Chapter may be preceded by the letters 'LR' in order to fully describe the grade, e.g. LR A, LR 490FG. LR LT-FH40, LR 316L , etc.
(c) When the material complies with the requirements of *Ch 3, 8 Plates with specified through thickness properties*, the grade is to include the suffix Z25 or Z35, e.g. LR AH36 Z35.
(d) Identification number and/or initials which will enable the full history of the item to be traced.
(e) If required by the purchaser, his order number or other identification mark.

The above particulars, but excluding the manufacturer's name or trade mark where this is embossed on finished products, are to be encircled with paint or otherwise marked so as to be easily recognisable.

1.11.2 Where a number of light materials are securely fastened together in bundles, the manufacturer may brand only the top piece of each bundle or, alternatively, a firmly fastened durable label containing the identification may be attached to each bundle.

1.11.3 In the event of any material bearing LR's brand failing to comply with the test requirements, the brand is to be unmistakably defaced, *see also Ch 1, 4.8 Identification of materials*.

1.12 Certification of materials

1.12.1 Unless a LR certificate is specified in other parts of the Rules, a manufacturer's certificate validated by LR is to be issued (*see Ch 1, 3.1 General*) and is to include the following particulars:

(a) Purchaser's name and order number.
(b) If known, the contract number for which the material is intended.
(c) Address to which material is dispatched.
(d) Name of steelworks.
(e) Description and dimensions of the material.
(f) Specification or grade of the steel.
(g) Identification number of piece, including test specimen number where appropriate.
(h) Cast number and chemical composition of ladle samples.
(i) Mechanical test results (not required on shipping statements).
(j) Condition of supply.

1.12.2 Before the test certificates are signed by the Surveyor, the steelmaker is required to provide a written declaration stating that the material has been made by an approved process, and that it has been subjected to and has withstood satisfactorily the required tests in the presence of the Surveyor, or an authorised deputy. The following form of declaration will be accepted if stamped or printed on each test certificate with the name of the steelworks and signed by an authorised representative of the manufacturer:

`We hereby certify that the material has been made by an approved process and satisfactorily tested in accordance with the Rules of Lloyd's Register'.

1.12.3 When steel is not produced at the works at which it is rolled, a certificate is to be supplied by the steelmaker stating the process of manufacture, the cast number and the chemical composition of ladle samples. The works at which the steel was produced must be approved by LR.

1.12.4 The manufacturer of coiled plate is required to issue a certificate which clearly identifies the material as coil. The certificate issued should include the words; 'Coils covered by this certificate require further processing at a works approved by Lloyd's Register before being certified as plate in accordance with the Rules of Lloyd's Register' in addition to the requirements of *Ch 3, 1.12 Certification of materials 1.12.2*.

1.12.5 The supplier of plate cut from coil is required to issue a certificate validated by the LR Surveyor which clearly identifies the product as finished plate meeting the requirements of the Rules in accordance with *Ch 3, 1.12 Certification of materials 1.12.2*.

1.12.6 The form of certificates produced by computer systems is to be agreed with the Surveyor.

■ *Section 2*
Normal strength steels for ship and other structural applications

2.1 Scope

2.1.1 The requirements of this Section are primarily intended to apply to steel plates and wide flats not exceeding 100 mm in thickness and sections and bars not exceeding 50 mm in thickness in Grades A, B, D and E. For greater thicknesses, variations in the requirements may be permitted or required for particular applications.

2.1.2 Additional approval tests may be required to verify the suitability for forming and welding of Grade E plate exceeding 50 mm in thickness.

2.2 Manufacture and chemical composition

2.2.1 The method of deoxidation and the chemical composition of ladle samples are to comply with the requirements given in *Table 3.2.1 Chemical composition and deoxidation practice*.

2.2.2 Small variations from the chemical compositions given in *Table 3.2.1 Chemical composition and deoxidation practice* may be allowed for Grade E steel in thicknesses exceeding 50 mm or when any Grade of steel is supplied in a thermo-mechanically controlled processed condition, provided that these variations are documented and approved in advance.

2.2.3 The manufacturer's declared analysis will be accepted subject to occasional checks if required by the Surveyors.

Table 3.2.1 Chemical composition and deoxidation practice

Grade	A	B	D	E
Deoxidation	For $t \leq 50$ mm: Any method (for rimmed steel, *see* Note 1)	For $t \leq 50$ mm: Any method except rimmed steel	For $t \leq 25$ mm: Killed	Killed and fine grain treated with aluminium
	For $t > 50$ mm: Killed	For $t > 50$ mm: Killed	For $t > 25$ mm: Killed and fine grain treated with aluminium	
Chemical composition % (*see* Note 5)				
Carbon	0,21 max. (*see* Note 2)	0,21 max.	0,21 max.	0,18 max.
Manganese	2,5 x C% min.	0,80 min. (*see* Note 3)	0,60 min.	0,70 min.
Silicon	0,50 max.	0,35 max.	0,10 – 0,35	0,10 – 0,35
Sulphur	0,035 max.	0,035 max.	0,035 max.	0,035 max.
Phosphorus	0,035 max.	0,035 max.	0,035 max.	0,035 max.
Aluminium (acid soluble)	-	-	0,015 min. (*see* Note 4)	0,015 min. (*see* Note 4)
	Carbon + 1 / 6 of the manganese content is not to exceed 0,40%			

Note 1. For Grade A, rimmed steel may only be accepted for sections up to a maximum thickness of 12,5 mm, provided that it is stated on the test certificates or shipping statements to be rimmed steel.

Note 2. The maximum carbon content for Grade A steel may be increased to 0,23% for sections.

Note 3. Where Grade B is impact tested the minimum manganese content may be reduced to 0,60%.

Note 4. The total aluminium content may be determined instead of the acid soluble content. In such cases the total aluminium content is to be not less than 0,020%.

Note 5. Where additions of any other elements are made as part of the steel-making practice, the content is to be recorded.

2.2.4 For plate supplied from coil, the chemical analysis can be transposed from the certificate of the coil manufacture onto the re-processor's certificate.

2.3 Condition of supply

2.3.1 All materials are to be supplied in a condition complying with the requirements given in *Table 3.2.2 Condition of supply*. Where alternative conditions are permitted these are at the option of the steelmaker, unless otherwise expressly stated in the order for the material, but a steelmaker is to supply materials only in those conditions for which he has been approved by LR.

Table 3.2.2 Condition of supply

Grade	Thickness mm	Conditions of supply			
A and B	≤50	Any			(*see* Note 1)
	>50 ≤100	N	NR	TM	(*see* Note 2)

D	≤35	Any			(*see* Note 1)
	>35 ≤100	N	NR	TM	(*see* Note 3)
E	≤100	N		TM	(*see* Note 4)

N= normalised

NR= normalising rolled

TM= thermomechanically controlled-rolled

Note 1. 'Any' includes as-rolled, normalised, normalising rolled and thermomechanically controlled-rolled.

Note 2. Plates, wide flats, sections and bars may be supplied in the as-rolled condition, subject to special approval from LR.

Note 3. Sections in Grade D steel may be supplied in thicknesses greater than 35 mm in the as-rolled condition provided that satisfactory results are consistently obtained from Charpy V-notch impact tests.

Note 4. Sections in Grade E steel may be supplied in the as-rolled and normalising rolled conditions provided that satisfactory results are consistently obtained from Charpy V-notch impact tests.

2.3.2 Where normalising rolling and thermomechanically controlled rolling (T.M.) processes are used, it is the manufacturer's responsibility to ensure that the programmed rolling schedules are adhered to. Where deviation from the programmed rolling schedule occurs, the manufacturer must ensure that each affected piece is tested and that the local Surveyor is informed.

2.3.3 If a steel product supplied in the T.M. condition is to be subjected to heating for forming or stress relieving or is to be welded by a high energy input process, consideration must be given to the possibility of a consequent reduction in mechanical properties.

2.4 Mechanical tests

2.4.1 The results of all tensile tests and the average energy value from each set of three impact tests are to comply with the appropriate requirements given in *Table 3.2.3 Mechanical properties for acceptance purposes* except where enhanced by the requirements of this Section.

2.4.2 With the exception given in *Ch 3, 2.4 Mechanical tests 2.4.4*, one tensile test is to be made for each batch presented unless the mass of finished material is greater than 50 tonnes, in which case one test is to be made from a different piece from each 50 tonnes or fraction thereof. Additional tests are to be made for every variation of 10 mm in the thickness or diameter of products from the same cast. For sections, the thickness to be considered is the thickness of the product at the point at which samples are taken for mechanical tests. A piece is to be regarded as the rolled product from a single slab or billet, or from a single ingot if this is rolled directly into plates, strip, sections or bars.

2.4.3 For Grades A and B where plate is supplied from coil, results of the tensile test can be transposed from the certificate of the coil manufacture onto the certificate issued by the re-processor. If the coil mass exceeds 50 tonnes, testing will additionally be required from two locations representing the start and end of the coil. For Grades D and E, the mechanical properties must be sampled from the decoiled plate in accordance with the frequency specified in the Rules.

2.4.4 For plates of thickness exceeding 50 mm in Grade E steel, one tensile test is to be made on each piece.

Table 3.2.3 Mechanical properties for acceptance purposes

Grade	Yield stress N/mm^2 minimum	Tensile strength N/mm^2	Elongation on 5,65 $\sqrt{S_o}$% minimum	Charpy V-notch impact test (*see* Notes 3, 4, 5, 6)		
				Thickness mm	Average energy J minimum	
					Longitudinal	Transverse
A, B, D, E	235	400 - 520 (see Note 1)	22 (see Note 2)	≤50	27	20
				>50≤70	34	24
				>70≤100	41	27

Impact tests are to be made on the various grades at the following temperatures:	A grade	not required
	B grade	0°C
	D grade	-20°C
	E grade	-40°C

Note 1. For sections in Grade A, the upper limit of the tensile strength range may be exceeded at the discretion of the Surveyor.

Note 2. For full thickness tensile test specimens with a width of 25 mm and a gauge length of 200 mm (*see Figure 2.2.4 Test specimen dimensions for plates, strip and sections - II*), the minimum elongation is to be:

Thickness mm	≤5	>5 ≤10	>10 ≤15	>15 ≤20	>20 ≤25	>25 ≤30	>30 ≤35	>35 ≤50
Elongation %	14	16	17	18	19	20	21	22

Note 3. *See Ch 3, 2.4 Mechanical tests 2.4.5* and *Ch 3, 2.4 Mechanical tests 2.4.6*.

Note 4. *See Ch 3, 2.4 Mechanical tests 2.4.7*.

Note 5. *See Ch 3, 1.8 Test material and mechanical tests 1.8.11*.

Note 6. *See Ch 3, 2.4 Mechanical tests 2.4.14*.

Thickness mm	≤5	>5 ≤10	>10 ≤15	>15 ≤20	>20 ≤25	>25 ≤30	>30 ≤35	>35 ≤50
Elongation %	14	16	17	18	19	20	21	22

2.4.5 For Grade A steel, Charpy V-notch impact tests are not required when the thickness does not exceed 50 mm, or up to 100 mm thick if the material is supplied in either the normalised or thermomechanically controlled-rolled condition and has been fine grain treated. However, the manufacturer should confirm, by way of regular in-house checks, that the material will meet a requirement of 27 J at +20 °C. The results of these checks shall be reported to the Surveyor. The frequency of these checks should as a minimum be every 250 tonnes.

2.4.6 When Grade A steel is supplied in a thickness greater than 50 mm and either, in the normalising rolled condition, or when special approval has been given to be supply in the as-rolled condition, a set of three impact test specimens is to be tested from each batch of 50 tonnes or fraction thereof.

2.4.7 Impact tests are not required for Grade B steel of 25 mm or less in thickness. However, the manufacturer is to confirm, by way of regular in-house tests, and on occasional material selected by the Surveyor, that the material meets the requirement in *Table 3.2.3 Mechanical properties for acceptance purposes*. The results of the tests are to be reported to the Surveyor. The frequency of the in-house checks are to be, as a minimum, one set of three impact test specimens for every 250 tonnes.

2.4.8 For Grade B steels of thicknesses above 25 mm, supplied in the as-rolled or normalising rolled condition, one set of three impact test specimens is to be made from the thickest item in each batch presented. If the mass of finished material is greater than 25 tonnes, one extra set of tests is to be made from a different piece from each 25 tonnes or fraction thereof.

2.4.9 For Grade B steels of thicknesses above 25 mm, supplied in the furnace normalised or thermomechanically controlled-rolled condition, one set of three impact test specimens is to be made from the thickest item in each batch presented. If the mass of finished material is greater than 50 tonnes, one extra set of tests is to be made from a different piece from each 50 tonnes or fraction thereof.

2.4.10 For Grade D steels supplied in the as-rolled or normalising rolled condition, one set of three impact test specimens is to be made from the thickest item in each batch presented. If the mass of finished material is greater than 25 tonnes, one extra set of tests is to be made from a different piece from each 25 tonnes or fraction thereof.

2.4.11 For Grade D steels, supplied in the furnace normalised or thermomechanically controlled-rolled condition, one set of three impact test specimens is to be made from the thickest item in each batch presented. If the mass of finished material is greater than 50 tonnes, one extra set of tests is to be made from a different piece from each 50 tonnes or fraction thereof.

2.4.12 For plates in Grade E steel, one set of three impact test specimens is to be made from each piece. For bars and sections in Grade E steel, one set of three test specimens is to be made from each 25 tonnes or fraction thereof. When, subject to the special approval of LR, sections are supplied in the as-rolled or normalising rolled conditions, one set of impact tests is to be taken from each batch of 15 tonnes or fraction thereof.

2.4.13 The results of all tensile tests and the average energy values from each set of three impact tests are to comply with the appropriate requirements given in *Table 3.2.3 Mechanical properties for acceptance purposes*. For impact tests, one individual value may be less than the required average value provided that it is not less than 70 per cent of this average value. *See Ch 1, 4.6 Re-test procedures* for re-test procedures.

2.4.14 For batch tested Grade B and D steel plates supplied in a condition other than furnace normalised, with a thickness equal to, or greater than 25 mm and 12 mm respectively, and where the average value of one set of tests is less than 40 J, two further items from the same batch are to be selected and tested. If these fail to achieve an average of 40 J on either set, each individual piece of the heat is to be tested. The plates are acceptable provided they meet the requirements of *Table 3.2.3 Mechanical properties for acceptance purposes*. Additional testing is not required where the manufacturer can demonstrate to the satisfaction of the Surveyor that the plate was rolled outside the limits of the programmed rolling schedule. In this instance the plate should be rejected, *see also Ch 3, 2.3 Condition of supply 2.3.2*.

2.4.15 Where standard subsidiary Charpy V-notch test specimens are necessary, *see Ch 2, 2.3 Procedure for testing at ambient temperature 2.3.4*.

2.5 Identification of materials

2.5.1 The particulars detailed in *Ch 3, 1.11 Identification of materials* are to be marked on all materials which have been accepted. Where a number of light materials are bundled, the bundle is to be identified in accordance with *Ch 3, 1.11 Identification of materials 1.11.2*.

2.6 Certification of materials

2.6.1 At least two copies of each test certificate are to be provided. They are to be of the type and give the information detailed in *Ch 3, 1.12 Certification of materials* and, additionally, are to indicate if sections in Grade A steel of rimming quality have been supplied. As a minimum, the chemical composition is to include the contents of any grain refining elements used and the residual elements, as detailed in *Table 3.2.1 Chemical composition and deoxidation practice*.

■ *Section 3*
Higher strength steels for ship and other structural applications

3.1 Scope

3.1.1 Provision is made for material to be supplied in four strength levels, 27S, 32, 36 and 40.

3.1.2 Provision is made for material specifically intended for hatch coamings and deck structure of container ships requiring specified crack arrest properties. Grades of steel of type EH40 in thicknesses above 85 mm and EH47 shall have crack arrest properties demonstrated at time of approval and at batch release. Crack arrest steels are to have a guaranteed crack arrest temperature (CAT) below -10°C.

3.1.3 The required notch toughness is designated by subdividing the strength levels into Grades AH, DH, EH and FH.

3.1.4 For the designation to fully identify a steel and its properties the appropriate grade letters should precede the strength level number, e.g. AH32 or FH40.

3.1.5 The requirements of this Section are primarily intended to apply to plates, wide flats, sections and bars not exceeding the thickness limits given in *Table 3.3.1 Maximum thickness limits*. For greater thicknesses, variations in the requirements may be permitted or required for particular applications but a reduction of the required impact energy is not allowed.

Table 3.3.1 Maximum thickness limits

Steel designation				Maximum thickness mm	
				Plates and wide flats	Sections and bars
AH 27S	DH 27S	EH 27S	FH27S	100	50
AH 32	DH 32	EH 32	FH32		
AH 36	DH 36	EH 36	FH36		
AH 40	DH 40	EH40 (*see* Note 1)	FH40		
EH 47 (see Note 1)					Not applicable

Note 1. Where the thickness of grade EH40 materials exceeds 85 mm the material is to achieve a crack arrest temperature (CAT) below -10°C. The CAT may be measured directly from large scale isothermal tests or be estimated from small scale tests that determine the Nil Ductility Temperature and applying a relationship such as the following, which has been validated at the approval stage:

$\mathrm{CAT} = (\mathrm{NDTT} + 10) + \left[\left(\frac{\ln \sigma}{0.046}\right) - 105\right] + \left[153(B - 5)^{1/13} - 190\right]$ where

CAT = crack arrest temperature in °C

NDTT = nil ductility test temperature in °C

σ = 2/3 of the minimum specified yield strength in N/mm^2

B = thickness of the plate in mm

As an alternative to crack arrest temperature, crack arrest properties may be demonstrated by large scale ESSO tests where Kca≥6000 $N/mm^{1.5}$ at -10°C or other approved methods.

Note 2. Minimum thickness for EH47 is 50 mm. The crack arrest properties of EH47 are to be determined as described in Note 1. Where the K_{ca} ESSO test is used and where the thickness of the steel exceeds 80 mm, the required K_{ca} value for the brittle crack arrest steel plate is to be specifically agreed with LR.

3.1.6 It should be noted that the fatigue strength of weldments in steels of high strength levels may not be greater than those of steels of lower strength levels.

3.2 Alternative specifications

3.2.1 Steels differing from the requirements of this Section in respect of chemical composition, deoxidation practice, condition of supply or mechanical properties may be accepted subject to special approval by LR. Such steels are to be given a special designation, *see Ch 3, 3.7 Identification of materials 3.7.2*.

3.3 Manufacture

3.3.1 All the grades of steel are to be in the killed and fine grain treated condition.

3.4 Chemical composition

3.4.1 The chemical compositions of ladle samples for all grades of steel are to comply with the requirements given in *Table 3.3.2 Chemical composition*. The requirements for H47 strength grade steels are given in *Table 3.3.3 Chemical composition for Grade EH 47*.

Table 3.3.2 Chemical composition

Grades	AH, DH, EH	FH
Carbon % max.	0,18	0,16
Manganese %	0,9 - 1,60 (*see* Note 1)	0,9 - 1,60
Silicon % max.	0,50	0,50
Phosphorus % max.	0,035	0,025
Sulphur % max.	0,035	0,025

Grain refining elements (*see* Note 2)		
Aluminium (acid soluble) %	0,015 min. (*see* Note 3)	
Niobium %	0,02 - 0,05	
Vanadium %	0,05 - 0,10	
Titanium %	0,02 max.	
Total (Nb + V + Ti) % (*see* Note 5)	0,12 max.	
Residual elements		
Nickel % max.	0,40	0,80
Copper % max.	0,35	0,35
Chromium % max.	0,20	0,20
Molybdenum % max.	0,08	0,08
Nitrogen % max.		0,009 (0,012 max. if Al is present)

Note 1. For AH grade steels in all strength levels and thicknesses up to 12,5 mm, the specified minimum manganese content is 0,70%.

Note 2. The steel is to contain aluminium, niobium, vanadium or other suitable grain refining elements, either singly or in any combination. When used singly, the steel is to contain the specified minimum content of the grain refining element. When used in combination, the specified minimum content of each element is not applicable.

Note 3. The total aluminium content may be determined instead of the acid soluble content. In such cases the total aluminium content is to be not less than 0,020%.

Note 4. Alloying elements other than those listed above are to be included in the approved manufacturing specification.

Note 5. The grain refining elements are to be in accordance with the approved specification.

Table 3.3.3 Chemical composition for Grade EH 47

Chemical element	max. (%)
Carbon	0,20
Manganese	2,00
Silicon	0,55
Phosphorus	0,030
Sulphur	0,030
Nickel	2,00
Chromium	0,25
Molybdenum	0,08
Grain refining elements (*see* Note 1) Aluminium (acid soluble)	0,015 min. (*see* Note 2)
Residual elements Copper	0,35

Note 1. The grain refining elements niobium, vanadium and titanium are to be in accordance with the approved specification.

Note 2. The total aluminium content may be determined instead of the acid soluble content. In these cases, the total aluminium content is to be not less than 0,020%.

3.4.2 The carbon equivalent is to be calculated from the ladle analysis using the formula given below and is not to exceed the maximum value agreed between the fabricator and the steelmaker when the steel is ordered.

$$Carbon equivalent = \mathrm{C} + \frac{\mathrm{Mn}}{6} + \frac{\mathrm{Cr} + \mathrm{Mo} + \mathrm{V}}{5} + \frac{\mathrm{Ni} + \mathrm{Cu}}{15}$$

For TM steels, the agreed carbon equivalent is not to exceed the values given in *Table 3.3.4 Carbon equivalent requirements for higher tensile strength steels up to 100 mm in thickness when supplied in the TM condition*.

3.4.3 The cold cracking susceptibility, P_{cm}, may be used instead of the carbon equivalent for evaluating weldability, in which case the following formula is to be used for calculating the P_{cm} from the ladle analysis:

$$P_{\mathrm{cm}} = \mathrm{C} + \frac{\mathrm{Si}}{30} + \frac{\mathrm{Mn} + \mathrm{Cr} + \mathrm{Cu}}{20} + \frac{\mathrm{Ni}}{60} + \frac{\mathrm{Mo}}{15} + \frac{\mathrm{V}}{10} + 5\mathrm{B}$$

The maximum allowable P_{cm} is to be agreed with LR and is to be included in the manufacturing specification and reported on the certificate.

3.4.4 The cold cracking susceptibility, P_{cm}, is to have a maximum value of 0,22 per cent for steels of H47 strength grade.

3.4.5 Small deviations in chemical composition from that given in *Table 3.3.2 Chemical composition* for plates exceeding 50 mm in thickness in Grades EH36, EH40, FH36 and FH40 may be approved provided that these deviations are documented and approved in advance.

3.4.6 Where the grain refining elements Niobium, Titanium and Vanadium are used either singly or in combination, the chemical composition is to be specifically approved for each Grade in combination with the rolling procedure to be used.

3.4.7 When any grade is supplied in an approved thermomechanically controlled processed condition, variations in the specified chemical composition may be considered, provided that these variations are documented and approved in advance.

3.4.8 For plate supplied from coil, the chemical analysis can be transposed from the certificate of the coil manufacture onto the re-processor's certificate.

Table 3.3.4 Carbon equivalent requirements for higher tensile strength steels up to 100 mm in thickness when supplied in the TM condition

Grades				Carbon Equivalent, max. (%)	
				$t \leq 50$	$50 < t \leq 100$
AH 27S	DH 27S	EH 27S	FH 27S	0,36	0,38
AH 32	DH 32	EH 32	FH 32	0,36	0,38
AH 36	DH 36	EH 36	FH 36	0,38	0,40
AH 40	DH 40	EH 40	FH 40	0,40	0,42
		EH 47		Not applicable (*see Table 3.3.1 Maximum thickness limits*)	0,49
Note t = thickness in mm.					

3.5 Condition of supply

3.5.1 All materials are to be supplied in a condition complying with the requirements given in *Table 3.3.5 Conditions of supply for plates and wide flats* or *Table 3.3.7 Conditions of supply for sections and bars*. Where alternative conditions are permitted, these are at the option of the steelmaker, unless otherwise expressly stated in the order for the material.

3.5.2 Where normalising rolling and thermomechanically controlled rolling (T.M.) processes are used, it is the manufacturer's responsibility to ensure that the programmed rolling schedules are adhered to. Where deviation from the programmed rolling schedule occurs, the manufacturer must ensure that each affected piece is tested and that the local Surveyor is informed.

3.5.3 The use of precipitation hardening steels is not acceptable, except where such hardening is incidental to the use of grain refining elements.

Table 3.3.5 Conditions of supply for plates and wide flats

Grade	Grain refining practice (*see* Note 1)	Thickness range mm	Conditions of supply (*see* Note 2)				
AH 27S AH 32 AH 36	Al or Al + Ti	≤20	AR	N	NR	TM	
		>20 ≤ 100	–	N	NR	TM	(*see* Note 3)
	Nb or V or Al + (Nb or V) or Al + (Ti) + (Nb or V)	≤12,5	AR	N	NR	TM	
		>12,5≤100	–	N	NR	TM	
AH 40	Any practice	≤12,5	AR	N	NR	TM	
		>12,5 ≤ 50	–	N	NR	TM	
		>50 ≤ 100	–	N	–	TM	QT
DH 27S DH 32 DH 36	Al or Al + Ti	≤20	AR	N	NR	TM	
		>20≤100	–	N	NR	TM	(*see* Note 4)
	Nb or V or Al + (Nb or V) or Al + (Ti) + (Nb or V)	≤12,5	AR	N	NR	TM	
		>12,5≤100	–	N	NR	TM	
DH 40	Any practice	≤50	–	N	NR	TM	
		> 50 ≤ 100	–	N	–	TM	QT
EH 27S EH 32 EH 36	Any practice	≤100	–	N	–	TM	
EH 40	Any practice	≤100	–	N	–	TM	QT
FH 27S FH 32 FH 36 FH 40	Any practice	≤100	–	N	–	TM	QT
EH 47	Any practice	≤50	Not applicable				
		>50 ≤100	—	—	—	TM	QT

Note 1. Grain refining elements used singly or in any combination, require specific approval from Materials and NDE Department, Southampton GTC Office.

Note 2. AR = as-rolled N = furnace normalised NR = normalising rolled TM = thermomechanically controlled-rolled QT = quenched and tempered.

Note 3. Material up to 35 mm thick may be supplied in the as-rolled condition provided that prior approval has been obtained from LR.

Note 4. Material up to 25 mm thick may be supplied in the as-rolled condition provided that prior approval has been obtained from LR.

3.6 Mechanical tests

3.6.1 The results of all tensile tests and the average energy value from each set of three Charpy V-notch impact tests are to comply with the appropriate requirements given in *Table 3.3.6 Mechanical properties for acceptance purposes (see Note 1)* .

Table 3.3.6 Mechanical properties for acceptance purposes (*see* Note 1)

Grades (*see*Note 3)	Yield Stress N/mm^{2}min.	Tensile Strength N/mm^{2}min.	Elongation on $5,65\sqrt{S_o}$ % min. (*see* Note 2)	Charpy V-notch impact tests (*see* Notes 3, 4, 5 and 6) Average energy J minimum					
				t ≤ 50mm		50 < t ≤ 70 mm		70 < t ≤ 100 mm	
				Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse
AH 27S DH 27S EH 27S FH 27S	265	400 - 530	22	27	20	34	24	41	27
AH 32 DH 32 EH 32 FH 32	315	440 - 570	22	31	22	38	26	46	31
AH 36 DH 36 EH 36 FH 36	355	490 - 630	21	34	24	41	27	50	34
AH 40 DH 40 EH 40 FH 40	390	510 - 650	20	39	26	46	31	55	37
EH 47	460	570 - 720	17	-	-	53	35	64 (*see*Note 1	42 (*see* Note 5)

Impact tests are to be made on the various grades at the following temperatures:

AH grades 0°C
DH grades -20°C
EH grades -40°C
FH grades -60°C

Note *1*. The requirements for products thicker than those detailed in the table are subject to agreement, *see Ch 3, 3.1 Scope 3.1.5*.

Note *2*. For full thickness tensile test specimens with a width of 25 mm and a gauge length of 200 mm, *see Ch 2, 2.1 Dimensions of test specimens 2.1.6* in Chapter 2, the minimum elongation is to be:

Thickness mm	≤5	>5 ≤10	>10 ≤15	>15 ≤20	>20 ≤25	>25 ≤30	>30 ≤40	>40 ≤50	>50

	Elongation	Strength levels 27S, 32	14	16	17	18	19	20	21	22	To be specifically agreed
		Strength level 36	13	15	16	17	18	19	20	21	
		Strength level 40	12	14	15	16	17	18	19	20	

Note *3*. Subject to special approval by LR, the minimum tensile strength may be reduced to 470 N/mm^2 , for grades AH36, DH36, EH36 and FH36, in the TM condition when micro-alloying elements Nb, Ti or V are used singly and not in combination and provided the yield to tensile strength ratio does not exceed 0,89. For plates with a thickness ≤12 mm, the yield to tensile strength ratio is to be specially considered.

Note *4*. *See Ch 3, 1.8 Test material and mechanical tests 1.8.11*

Note *5*. For steel of H47 strength grade, the yield to tensile strength ratio is not to exceed 0,94.

Note *6*. The Charpy V-notch impact energy for EH47 in thickness between 85 mm and 100 mm are to be 75J in the longitudinal direction and 50J in the transverse direction

3.6.2 For steels in the as-rolled, normalised, normalising rolled or T.M. conditions, one tensile test is to be made for each batch of 50 tonnes or fraction thereof. Additional tests are to be made for every variation of 10 mm in the thickness or diameter of products from the same cast.

3.6.3 Where plate is supplied from coil, both the tensile tests and the Charpy V-notch tests are to be taken from the de-coiled plate in accordance with the frequency specified for the Grade as required by this Section.

3.6.4 For steels in the quenched and tempered condition a tensile test is to be made on each plate as heat treated. For continuously heat treated plates, one tensile test is to be made for each 50 tonnes or fraction thereof from a single cast. Additional tests are to be made for every variation of 10 mm in the thickness of the products from a single cast. The tensile test specimens are to be taken with their axes transverse to the main direction of rolling.

3.6.5 For products in the AH and DH grades, at least one set of three impact tests is to be made on the thickest piece in each batch of 50 tonnes when supplied in either the normalised or thermomechanically controlled condition. When the products are supplied in the as-rolled or normalising rolled conditions a set of impact test specimens is to be taken from a different piece from each 25 tonnes or fraction thereof. When supplied in the quenched and tempered condition, a set of impact tests is to be made on each length as heat treated. Test specimens from the quenched and tempered plates are to have their axes transverse to the main rolling direction.

3.6.6 For plates and wide flats in the EH and FH grades supplied in the normalised or thermomechanically controlled conditions, one set of impact tests is to be made on each piece. For plates supplied in the quenched and tempered condition a set of impact tests is to be made on each length as heat treated. Test specimens from the quenched and tempered plates are to have their axes transverse to the main rolling direction.

3.6.7 For crack arrest steels the brittle crack arrest test frequency is to be as stated in *Ch 3, 3.6 Mechanical tests 3.6.6*. Small scale test methods may be used to demonstrate brittle crack arrest properties, subject to approval of the test method prior to application

3.6.8 For sections and bars in the EH and FH grades supplied in the normalised or thermomechanically controlled conditions, one set of impact tests is to be made on the thickest piece in a batch not exceeding 25 tonnes. For sections supplied in the as-rolled or normalising rolled conditions the batch size is not to exceed 15 tonnes.

Table 3.3.7 Conditions of supply for sections and bars

Grade	Grain refining practice (*see* Note 1)	Thickness range mm	Conditions of supply (*see* Note 2)
AH 27S, AH 32, AH 36	Al or Al + Ti	≤20	Any
		>20≤50	N NR TM (*see* Note 3)
	Nb or V or Al + Nb or A1+ V or Al + (Ti) + (Nb or V)	≤12,5	Any
		>12,5≤50	N NR TM (*see* Note 3)
AH 40	Any practice	≤12,5	Any
		>12,5≤50	N NR TM
DH 27S, DH 32, DH 36	Al or Al + Ti	≤20	Any
		>20≤50	N NR TM (*see* Note 3)
	Nb or V or Al + Nb or Al + V or Al + (Ti) + (Nb or V)	≤12,5	Any
		>12,5≤50	N NR TM (*see* Note 3)
DH 40	Any practice	≤50	N NR TM
EH 27S, EH 32, EH 36	Any practice	≤50	N TM (*see* Notes 3 and 4)
EH 40	Any practice	≤50	N TM QT
FH 27S, FH 32, FH 36, FH 40	Any practice	≤50	N TM QT (*see* Note 4)

Note 1. Grain refining elements used singly or in any combination require specific approval from Materials and NDE Department, Southampton GTC Office.

Note 2. N = furnace normalised NR = normalising rolled TM = thermomechanically controlled-rolled QT = quenched and tempered

Note 3. Subject to the special approval of LR, sections may be supplied in the as-rolled condition provided satisfactory results are consistently obtained from Charpy V-notch impact tests.

Note 4. Subject to the special approval of LR, sections may be supplied in the NR condition.

3.6.9 Where standard subsidiary impact specimens are necessary, *see Ch 2, 2.3 Procedure for testing at ambient temperature 2.3.4*.

3.7 Identification of materials

3.7.1 The particulars detailed in *Ch 3, 1.11 Identification of materials* are to be marked on all materials which have been accepted and, for ease of recognition, are to be encircled or otherwise marked with paint. Where a number of light products are bundled, the bundle is to be identified in accordance with *Ch 3, 1.11 Identification of materials 1.11.2*.

3.7.2 Steels which have been specially approved and which differ from the requirements of this Section are to have the letter `S' after the agreed identification mark.

3.8 Certification of materials

3.8.1 At least two copies of each test certificate are to be provided. They are to be of the type and give the information detailed in *Ch 3, 1.12 Certification of materials* and, additionally, are to state the specified maximum carbon equivalent. As a minimum, the chemical composition is to include the contents of any grain refining elements used and of the residual elements.

3.8.2 For steels which have been specially approved, the agreed identification mark, the specified minimum yield stress and, if applicable, the contents of alloying elements are additionally to be stated on the test certificate or shipping statement.

3.8.3 The steelmaker is to provide the Surveyor with a written declaration as detailed in *Ch 3, 1.12 Certification of materials 1.12.2*.

■ *Section 4*
Steels for boilers and pressure vessels

4.1 Scope

4.1.1 Provision is made in this Section for carbon, carbon-manganese and alloy steels intended for use in the construction of boilers and pressure vessels. In addition to specifying mechanical properties at ambient temperature for the purposes of acceptance testing, these requirements also give details of appropriate mechanical properties at elevated temperatures which may be used for design purposes.

4.1.2 Where it is proposed to use a carbon or carbon-manganese steel with a specified minimum tensile strength intermediate to those given in this Section, corresponding minimum values for the yield stress, elongation and mechanical properties at elevated temperatures may be obtained by interpolation.

4.1.3 Carbon and carbon-manganese steels with a specified minimum tensile strength of greater than 490 N/mm^2 but not exceeding 520 N/mm^2 may be accepted, provided that details of the proposed specification are submitted for approval.

4.1.4 Where it is proposed to use alloy steels other than as given in this Section, details of the specification are to be submitted for approval. In such cases the specified minimum tensile strength is not to exceed 600 N/mm^2.

4.1.5 Materials intended for use in the construction of the cargo tanks and process pressure vessels storage tanks for liquefied gases and for other low temperature applications are to comply with the requirements of *Ch 3, 6 Ferritic steels for low temperature service* or *Ch 3, 7 Austenitic and duplex stainless steels*, as appropriate.

4.2 Manufacture and chemical composition

4.2.1 The method of deoxidation and the chemical composition of ladle samples are to comply with the appropriate requirements of *Table 3.4.1 Chemical composition and deoxidation practice*.

Table 3.4.1 Chemical composition and deoxidation practice

Grade of steel	Deoxidation	Chemical composition %						
Carbon and carbon-manganese steels		C max.	Si	Mn	P	S	Al	Residual elements
360 AR	Any method except rimmed steel	0,18	0, 50 max.	0,40 – 1,20	0,040 max.		-	Cr 0,25 max. Cu 0,30 max. Mo 0,10 max. Ni 0,30 max. Total 0,70 max.
410 AR		0,21		0,40 – 1,30			-	
460 AR		0,23		0,80 – 1,50			-	
360	Any method except rimmed steel	0,17	0,35 max.	0,40 – 1,20	0,035 max.		-	
410		0,20		0,50 – 1,30			-	
460		0,20 (*see* Note 1)	0,40 max.	0,80 – 1,40			-	
490	Killed		0,10 – 0,50	0,90 – 1,60			-	
360 FG	Killed fine grained	0,17	0,35 max.	0,40 – 1,20	0,035 max.		(*see* Note 2)	
410 FG		0,20		0,50 – 1,30				
460 FG		0,20 (*see* Note 1)	0,40 max.	0,80 – 1,50				
490 FG			0,10 – 0,50	0,90 – 1,60				
510 FG		0,22						

Alloy steel		C	Si	Mn	P S	Al	Cr	Mo	Residual Elements
13Cr Mo 45	Killed	0,10–0,18	0,15-0,35	0,4-0,8	0,035 max.	(*see* Note 3)	0,70-1,30	0,40-0,60	Cu 0,30 max.
11Cr Mo 910		0,08-0,18	0,15-0,50				2,00-2,50	0,90-1,10	Ni 0,30 max.

Note 1. For thicknesses greater than 30 mm, carbon 0,22% max.

Note 2. Aluminium (acid soluble) 0,015% min. or Aluminium (total) 0,018% min.

Niobium, vanadium or other suitable grain refining elements may be used either in place of or in addition to aluminium.

Note 3.Aluminium (acid soluble or total) 0,020% max.

4.2.2 For plate supplied from coil, the chemical analysis may be transposed from the certificate of the coil manufacture onto the re-processor's certificate.

4.3 Heat treatment

4.3.1 All materials are to be supplied in a condition complying with the requirements given in *Table 3.4.2 Condition of supply* except that, when agreed, material intended for hot forming may be supplied in the as-rolled condition.

Table 3.4.2 Condition of supply

Grade of steel	Condition of supply
Carbon and carbon-manganese 360 AR to 460 AR	As-rolled Maximum thickness or diameter is 40 mm

Carbon and carbon-manganese 360 to 490	Normalised or normalised rolled
Carbon and carbon-manganese 360 FG to 510 FG	Normalised or normalised rolled
13Cr Mo 45	Normalised and tempered
11Cr Mo 910	Normalised and tempered

4.4 Mechanical tests

4.4.1 For plates, a tensile test specimen is to be taken from one end of each piece when the mass does not exceed 5 tonnes and the length does not exceed 15 m. When either of these limits is exceeded, tensile test specimens are to be taken from both ends of each piece. A piece is to be regarded as the rolled product from a single slab or from a single ingot if this is rolled directly into plates.

4.4.2 For strip, tensile test specimens are to be taken from both ends of each coil.

4.4.3 Sections and bars are to be presented for acceptance test in batches containing not more than 50 lengths, as supplied. The material in each batch is to be of the same section size, from the same cast and in the same condition of supply. One tensile test specimen is to be taken from material representative of each batch, except that additional tests are to be taken when the mass of a batch exceeds 10 tonnes.

4.4.4 Where plates are required for hot forming and it has been agreed that the heat treatment will be carried out by the fabricator, the tests at the steelworks are to be made on material which has been cut from the plates and given a normalising and tempering heat treatment in a manner simulating the treatment which will be applied to the plates.

4.4.5 If required by the Surveyors or by the fabricator, test material may be given a simulated stress relieving heat treatment prior to the preparation of the test specimens. This has to be stated on the order together with agreed details of the simulated heat treatment and the mechanical properties which can be accepted.

4.4.6 The results of all tensile tests are to comply with the appropriate requirements given in *Table 3.4.3 Mechanical properties for acceptance purposes: carbon and carbon-manganese steels - As-rolled* to *Table 3.4.5 Mechanical properties for acceptance purposes: alloy steels - Normalised and tempered*.

Table 3.4.3 Mechanical properties for acceptance purposes: carbon and carbon-manganese steels - As-rolled

Grade of steel	Thickness mm	Yield stress N/mm^2 minimum	Tensile strength N/mm^2	Elongation on 5,65 $\sqrt{S_0}$ % minimum
360 AR	≤40	190	360–480	24
410 AR	≤40	215	410–530	22
460 AR	≤40	240	460–580	21

Table 3.4.4 Mechanical properties for acceptance purposes: carbon and carbon-manganese steels - Normalised or normalised rolled

Grade of steel	Thickness mm (*see* Note)	Yield stress N/mm^2 minimum	Tensile strength N/mm^2	Elongation on 5,65 $\sqrt{S_0}$ % minimum
360	>3≤16	205	360 – 480	26
	>16≤40	195		26
	>40≤63	185		25

410	>3≤16 >16≤40 >40≤63	235 225 215	410 – 530	24 24 23
460	>3≤16 >16≤40 >40≤63	285 255 245	460 – 580	22 22 21
490	>3≤16 >16≤40 >40≤63	305 275 265	490 – 610	21 21 20
360 FG	>3≤16 >16≤40 >40≤63	235 215 195	360 – 480	26 26 25
410 FG	>3≤16 >16≤40 >40≤63	265 245 235	410 – 530	24 24 23
460 FG	>3≤16 >16≤40 >40≤63	295 285 275	460 – 580	22 22 21
490 FG	>3≤16 >16≤40 >40≤63	315 315 305	490 – 610	21 21 21
510 FG	>3≤16 >16≤40 >40≤63	355 345 335	510 – 650	21
Note For thicknesses greater than 63 mm, the minimum values for yield stress may be reduced by 1% for each 5 mm increment in thickness over 63 mm. The minimum elongation values may also be reduced one unit, for all thicknesses over 63 mm. For thicknesses over 100 mm, the above values are to be agreed.				

4.4.7 Where plate is supplied from coil, the tensile tests are to be taken from the de-coiled plate in accordance with the frequency specified for the Grade as required by this Section.

Table 3.4.5 Mechanical properties for acceptance purposes: alloy steels - Normalised and tempered

Grade of steel	Thickness mm (*see* Note)	Yield stress N/mm^2 minimum	Tensile strength N/mm^2	Elongation on 5,65 $\sqrt{S_o}$ % minimum
13Cr Mo45	≤63	305	470-620	20
11Cr Mo910	≤16	275	480-630	18

11Cr Mo910	>16≤63	265	480-630	18
Note For thicknesses greater than 63 mm, the minimum values for yield stress may be reduced by 1% for each 5 mm increment in thickness over 63 mm. The minimum elongation values may also be reduced one unit, e.g. for all thicknesses over 63 mm. For thicknesses over 100 mm, the above values are to be agreed.				

4.4.8 All test specimens are to be taken in the transverse direction unless otherwise agreed.

4.4.9 When material will be subject to strains in a through thickness direction, it is recommended that it should have specified through thickness properties in accordance with the requirements of *Ch 3, 8 Plates with specified through thickness properties*.

4.5 Identification of materials

4.5.1 The particulars detailed in *Ch 3, 1.11 Identification of materials* are to be marked on all materials which have been accepted.

4.6 Certification of materials

4.6.1 At least two copies of each test certificate are to be provided. They are to be of the type and to give the information detailed in *Ch 3, 1.12 Certification of materials* and, additionally, are to state the specified maximum carbon equivalent. As a minimum, chemical composition is to include the content of any grain refining elements used and of the residual elements, as detailed in *Table 3.4.1 Chemical composition and deoxidation practice*.

4.7 Mechanical properties for design purposes

4.7.1 Nominal values for the minimum lower yield or 0,2 per cent proof stress at temperatures of 50°C and higher are given in *Table 3.4.6 Mechanical properties for design purposes (see 4.7.1) : carbon and carbon-manganese steels - As-rolled* to *Table 3.4.8 Mechanical properties for design purposes (see 4.7.1): alloy steels - Normalised and tempered* .

Table 3.4.6 Mechanical properties for design purposes (*see* 4.7.1) : carbon and carbon-manganese steels - As-rolled

Grade of steel	Thickness mm	Design temperature °C (*see* Note)						
		50	100	150	200	250	300	350
		Nominal minimum lower yield or 0,2% proof stress N/mm^2						
360 AR	≤40	154	153	152	145	128	108	102
410 AR	≤40	186	183	181	174	155	134	127
460 AR	≤40	218	213	210	203	182	161	153
Note Maximum permissible design temperature is 350°C								

4.7.2 These values are intended for design purposes only, and verification is not required except for materials complying with National or proprietary specifications where the elevated temperature properties used for design purposes are higher than given in *Table 3.4.6 Mechanical properties for design purposes (see 4.7.1) : carbon and carbon-manganese steels - As-rolled* to *Table 3.4.8 Mechanical properties for design purposes (see 4.7.1): alloy steels - Normalised and tempered* .

4.7.3 In such cases, at least one tensile test at the proposed design or other agreed temperature is to be made on material from each cast. Where materials of more than one thickness are supplied from one cast, the thickest material is to be tested. The test specimens are to be prepared from material adjacent to that used for tests at ambient temperature. The axis of the test specimens is to be between mid and quarter thickness of the material and the test specimens are to be machined to dimensions in accordance with the requirements of *Ch 2 Testing Procedures for Metallic Materials*. The test procedure is also to be as detailed in *Ch 2 Testing Procedures for Metallic Materials*, and the results are to comply with the requirements of the National or proprietary specifications.

4.7.4 As an alternative to *Ch 3, 4.7 Mechanical properties for design purposes 4.7.3*, a manufacturer may carry out an agreed comprehensive test program for a stated grade of steel to demonstrate that the specified minimum mechanical properties at elevated temperatures can be consistently obtained. This test program is to be carried out under supervision of the Surveyors, and the results submitted for assessment and approval. When a manufacturer is approved on this basis, tensile tests at elevated temperatures are not required for acceptance purposes but, at the discretion of the Surveyors, occasional check tests of this type may be requested.

4.7.5 Values for the estimated average stress to rupture in 100 000 hours are given in *Table 3.4.9 Mechanical properties for design purposes (see 4.7.5): estimated average values for stress to rupture in 100 000 hours (units N/mm²)* and may be used for design purposes.

Table 3.4.7 Mechanical properties for design purposes (*see* 4.7.1): carbon and carbon-manganese steels - Normalised or controlled-rolled

Grade of steel	Thickness mm (see Note)	Design temperature °C								
		50	100	150	200	250	300	350	400	450
		Nominal minimum lower yield or 0,2% proof stress N/mm^2								
360	>3≤16	183	175	172	168	150	124	117	115	113
	>16≤40	173	171	169	162	144	124	117	115	113
	>40≤63	166	162	158	152	141	124	117	115	113
410	>3≤16	220	211	208	201	180	150	142	138	136
	>16≤40	204	201	198	191	171	150	142	138	136
	>40≤63	196	192	188	181	168	150	142	138	136
460	>3≤16	260	248	243	235	210	176	168	162	158
	>16≤40	235	230	227	220	198	176	168	162	158
	>40≤63	227	222	218	210	194	176	168	162	158
490	>3≤16	280	270	264	255	228	192	183	177	172
	>16≤40	255	248	245	237	214	192	183	177	172
	>40≤63	245	240	236	227	210	192	183	177	172
360 FG	>3≤16	214	204	185	165	145	127	116	110	106
	>16≤40	200	196	183	164	145	127	116	110	106
	>40≤63	183	179	172	159	145	127	116	110	106
410 FG	>3≤16	248	235	216	194	171	152	141	134	130
	>16≤40	235	228	213	192	171	152	141	134	130
	>40≤63	222	215	204	188	171	152	141	134	130
460 FG	>3≤16	276	262	247	223	198	177	167	158	153
	>16≤40	271	260	242	220	198	177	167	158	153
	>40≤63	262	251	235	217	198	177	167	158	153
490 FG	>3≤16	297	284	265	240	213	192	182	173	168
	>16≤40	293	279	260	237	213	192	182	173	168
	>40≤63	286	272	256	234	213	192	182	173	168
510 FG	>3≤63	313	290	270	255	235	215	200	180	–

Note For thicknesses greater than 63 mm, the values for lower yield or 0,2% proof stress are to be reduced by 1% for each 5 mm increment in thickness up to 100 mm. For thicknesses over 100 mm, the values are to be agreed and verified by test.

Table 3.4.8 Mechanical properties for design purposes (*see* 4.7.1): alloy steels - Normalised and tempered

Grade of steel	Thickness mm (see Note)	Design temperature °C									
		50	100	200	300	350	400	450	500	550	600
		Nominal minimum lower yield or 0,2% proof stress N/mm^2									
13Cr Mo45	>3≤63	284	270	248	216	203	199	194	188	181	174
11Cr Mo910	>3≤63	255	249	233	219	212	207	194	180	160	137
Note For thicknesses greater than 63 mm, the values for lower yield or 0,2% proof stress are to be reduced by 1% for each 5 mm increment in thickness up to 100 mm. For thicknesses over 100 mm, the values are to be agreed and verified by test.											

Table 3.4.9 Mechanical properties for design purposes (*see* 4.7.5): estimated average values for stress to rupture in 100 000 hours (units N/mm^2)

Temperature °C	Grades of steel				
	Carbon and carbon-manganese			Low alloy	
	360FG 410FG 460FG	360 410 460	490 490FG 510FG	13CrMo 45	11CrMo 910
380	171	219	227	-	-
390	155	196	203	-	-
400	141	173	179	-	-
410	127	151	157	-	-
420	114	129	136	-	-
430	102	109	117	-	-
440	90	92	100	-	-
450	78	78	85	290	-
460	67	67	73	262	-
470	57	57	63	235	210
480	47	48	55	208	186
490	36	-	47	181	165
500	-	-	-	155	145
510	-	-	-	129	128
520	-	-	-	103	112
530	-	-	-	80	98
540	-	-	-	62	84
550	-	-	-	49	72
560	-	-	-	42	61

570	-	-	-	36	51
580	-	-	-	-	44

Section 5
Steels for machinery fabrications

5.1 General

5.1.1 Steel plates, sections or bars intended for use in the construction of major components of welded machinery structures, such as bedplates, crankcases, frames and entablatures, are to comply with one of the following alternatives:

(a) Any grade of normal strength structural steel as detailed in *Ch 3, 2 Normal strength steels for ship and other structural applications*.
(b) Any grade of higher tensile structural steel as detailed in *Ch 3, 3 Higher strength steels for ship and other structural applications*.
(c) Any grade of carbon-manganese boiler or pressure vessel steel as detailed in *Ch 3, 4 Steels for boilers and pressure vessels*, except that for this application batch testing is acceptable. The size of a batch and the number of tensile tests are to be as detailed in *Ch 3, 2 Normal strength steels for ship and other structural applications*.

5.1.2 The minus tolerances for products for machinery structures are to be in accordance with *Table 3.5.1 Under thickness tolerances*.

Table 3.5.1 Under thickness tolerances

Nominal thickness, t (mm)	Minus tolerance (mm)
$5 \leq t < 8$	–0,4
$8 \leq t < 15$	–0,5
$15 \leq t < 25$	–0,6
$25 \leq t < 40$	–0,8
$t \geq 40$	–1,0

5.2 Certification of materials

5.2.1 At least two copies of each test certificate are to be provided. They are to be of the type and give the information detailed in *Ch 3, 1.12 Certification of materials* and, additionally, are to state the specified maximum carbon equivalent. As a minimum, chemical composition is to include the contents of any grain refining elements used and of the residual elements.

Section 6
Ferritic steels for low temperature service

6.1 Scope

6.1.1 This Section gives specific requirements for carbon-manganese and nickel alloy steels intended for use in the construction of cargo tanks, storage tanks and process pressure vessels for liquefied gases.

6.1.2 The requirements of this Section are also applicable for other types of pressure vessels where the use of steels with guaranteed impact properties at low temperatures is required.

6.1.3 Provision is made for plates and sections up to 40 mm thick.

6.1.4 Steels with alternative chemical compositions or mechanical properties or in a different supply condition may be given special consideration.

6.2 Manufacture and chemical composition

6.2.1 All steels are to be in the killed and fine grain treated condition.

6.2.2 The chemical compositions of carbon-manganese steels are to comply with the appropriate requirements for grades AH, DH, EH and FH strength levels 27S, 32, 36 and 40,*see Table 3.3.2 Chemical composition*. For the uses defined in *Ch 3, 6.1 Scope 6.1.1* and *Ch 3, 6.1 Scope 6.1.2*, however, these grades are to be designated LT–AH, LT–DH, LT–EH and LT–FH respectively.

6.2.3 The chemical compositions of nickel alloy steels are to comply with the appropriate requirements of *Table 3.6.1 Chemical compositions of nickel alloy steels*.

Table 3.6.1 Chemical compositions of nickel alloy steels

<table>
<tr><th>Grade of steel</th><th>C</th><th>Si</th><th>Mn</th><th>Ni</th><th>P</th><th>S</th><th>Residual elements</th><th>Aluminium</th></tr>
<tr><td>1 1/2 Ni</td><td>0,18 max.</td><td rowspan="5">0,10 – 0,35</td><td>0,30 – 1,50</td><td>1,30 – 1,70</td><td rowspan="5">0,025 max.</td><td rowspan="5">0,020 max.</td><td rowspan="5">Cr 0,25 max.
Cu 0,35 max.
Mo 0,08 max.
Total 0,60 max.</td><td rowspan="5">Total 0,020% min.
Acid soluble 0,015% min.</td></tr>
<tr><td>2 1/4 Ni</td><td>0,18 max</td><td>0.30 - 0.80</td><td>2.10 - 2.50</td></tr>
<tr><td>3 1/2 Ni</td><td>0,15 max.</td><td rowspan="3">0,30 – 0,90</td><td>3,20 – 3,80</td></tr>
<tr><td>5Ni</td><td>0,12 max.</td><td>4,70 – 5,30</td></tr>
<tr><td>9Ni</td><td>0,10 max.</td><td>8,50 – 10,0</td></tr>
</table>

6.2.4 For plate supplied from coil, the chemical analysis may be transposed from the certificate of the coil manufacture onto the re-processor's certificate.

6.3 Heat treatment

6.3.1 All materials are to be supplied in a condition complying with the requirements given in *Table 3.6.2 Supply conditions*.

Table 3.6.2 Supply conditions

<table>
<tr><th>Grade</th><th>Plates</th><th>Sections and bars</th></tr>
<tr><td>LT – AH</td><td rowspan="2">N TM</td><td rowspan="3">Any</td></tr>
<tr><td>LT – DH</td></tr>
<tr><td>LT – EH</td><td rowspan="2">Normalised (see Note) T.M.C.P. Quenched and tempered</td></tr>
<tr><td>LT – FH</td><td>N TM</td></tr>
<tr><td>1 1/2 Ni
2 1/4 Ni
3 1/2 Ni
5Ni</td><td colspan="2">Normalised (see Note)
Normalised or Normalised and tempered
Normalised and tempered
Quenched and tempered</td></tr>
<tr><td>9Ni</td><td colspan="2">Double normalised and tempered Quenched and tempered</td></tr>
<tr><td colspan="3">Note Where the term ‘Normalised’ is used it does not include normalising rolling.</td></tr>
</table>

6.4 Mechanical tests

6.4.1 For plates, tensile test specimens are to be taken from both ends of each piece. A piece is to be regarded as the rolled product from a single slab or from a single ingot if this is rolled directly into plates.

6.4.2 For strips, tensile test specimens are to be taken from both ends of each coil.

6.4.3 Sections and bars are to be presented for acceptance test in batches containing not more than 50 lengths, as supplied. The material in each batch is to be of the same section size, from the same cast and in the same condition of supply. One tensile test specimen is to be taken from material representative of each batch, except that additional tests are to be taken when the mass of a batch exceeds 10 tonnes.

6.4.4 One set of three Charpy V-notch impact test specimens is to be taken for each tensile test specimen required.

6.4.5 For plates, these impact test specimens are to be cut with the principal axis perpendicular to the final direction of rolling. For sections, the impact test specimens are to be taken longitudinally.

6.4.6 The results of all tensile tests are to comply with the appropriate requirements given in *Table 3.6.3 Mechanical properties for acceptance purposes (see Note 1)* . The ratio between the yield stress and the tensile strength is not to exceed 0,9 for normalised and TM steels and 0,94 for QT steels.

Table 3.6.3 Mechanical properties for acceptance purposes (*see* Note 1)

Grade of steel		Yield stress N/mm^2 min.	Tensile strength N/mm^2	Elongation on 5.65 $\sqrt{S_o}$ % min.	Charpy V-notch impact tests (*see* Note 3)	
					Test temp. °C	Impact energy
LT – AH	27S	265	400 – 530	22	0	Plates – transverse tests Average energy 27 J min Sections and bars – longitudinal tests Average energy 41 J min
	32	315	440 – 590	22		
	36	355	490 – 620	21		
	40	390	510 – 650	20		
LT – DH	27S	265	400 – 530	22	–20	
	32	315	440 – 590	22		
	36	355	490 – 620	21		
	40	390	510 – 650	20		
LT – EH	27S	265	400 – 530	22	–40	
	32	315	440 – 590	22		
	36	355	490 – 620	21		
	40	390	510 – 650	20		
LT – FH	27S	265	400 – 530	22	–60	
	32	315	440 – 590	22		
	36	355	490 – 620	21		
	40	390	510 – 650	20		
$1^1/_2$ Ni		275	490 – 640	22	–65	
$2\ ^1/_4$ Ni		275	490 - 640	21	-70	
$3^1/_2$ Ni		285	450 – 610	21	–95	
5Ni		390	540 – 740	21	–110	

9Ni	490	640 – 790	18	–196	
Note 1. These requirements are applicable to products not exceeding 40 mm in thickness. The requirements for thicker products are subject to agreement.					
Note 2. The minimum design temperatures at which plates of different thicknesses in the above grades may be used are given in *Figure 3.6.1 Minimum design temperatures for carbon-manganese grades* and *Figure 3.6.2 Minimum design temperatures for nickel grades*. Consideration will be given to the use of thicknesses greater than those in the Tables or to the use of design temperatures below –165°C.					
Note 3. *See Ch 3, 1.8 Test material and mechanical tests 1.8.11*					

6.4.7 The average value for the three impact tests is to comply with the appropriate requirements given in *Table 3.6.3 Mechanical properties for acceptance purposes (see Note 1)* . One individual value may be less than the required value provided that it is not less than 70 per cent of this average value. *See Ch 2, 1.4 Re-testing procedures* for re-test procedures.

6.4.8 Where standard subsidiary impact specimens are necessary, *see Ch 2, 2.3 Procedure for testing at ambient temperature 2.3.4*.

6.4.9 Where plate is supplied from coil, both the tensile tests and the Charpy V-notch tests are to be taken from the de-coiled plate in accordance with the frequency specified for the Grade as required by this Section.

6.5 Identification of materials

6.5.1 The particulars detailed in *Ch 3, 1.11 Identification of materials* are to be marked on all materials which have been accepted.

6.6 Certification of materials

6.6.1 At least two copies of each test certificate are to be provided. They are to be of the type and give the information detailed in *Ch 3, 1.12 Certification of materials* together with general details of the heat treatment. As a minimum, chemical composition is to include the contents of any grain refining elements used and the residual elements as detailed in *Table 3.3.2 Chemical composition* or *Table 3.6.1 Chemical compositions of nickel alloy steels*.

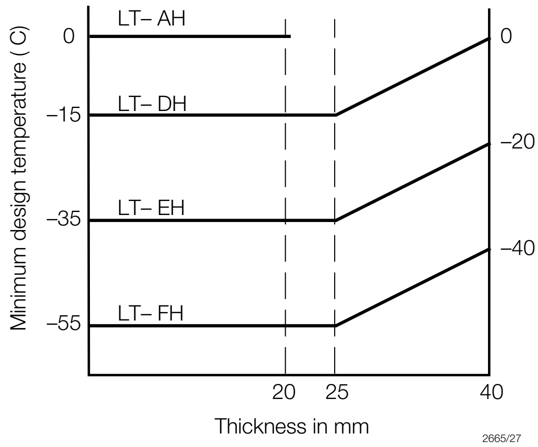


Figure 3.6.1 Minimum design temperatures for carbon-manganese grades

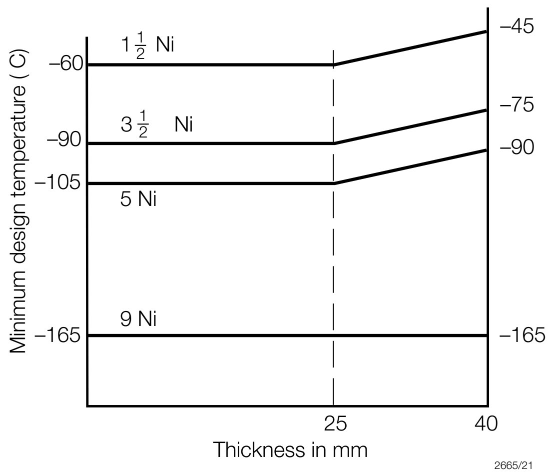


Figure 3.6.2 Minimum design temperatures for nickel grades

Section 7
Austenitic and duplex stainless steels

7.1 Scope

7.1.1 Provision is made in this Section for rolled products in austenitic and duplex (austenite plus ferrite) stainless steels intended for use in the construction of cargo tanks, storage tanks and process pressure vessels for chemicals and liquefied gases.

7.1.2 Austenitic stainless steels are suitable for applications where the lowest design temperature is not lower than –165°C.

7.1.3 Austenitic stainless steels are also suitable for service at elevated temperatures, and for such applications the proposed specification should contain, in addition to the requirements of *Ch 3, 7.1 Scope 7.1.6*, minimum values for 0,2 and 1,0 per cent proof stresses at the design temperature.

7.1.4 Duplex stainless steels are suitable for applications where the lowest design temperature is above 0°C. Any requirement to use duplex stainless steels below 0°C will be subject to special consideration.

7.1.5 Duplex stainless steels are also suitable for service at temperatures up to 300°C, and for such applications the proposed specification should include, in addition to the requirements of 7.1.6, a minimum value for 0,2 per cent proof stress at the design temperature.

7.1.6 A specification giving details of the chemical composition, heat treatment and mechanical properties, including, for the austenitic grades, both the 0,2 and 1,0 per cent proof stresses, is to be submitted for consideration and approval.

7.2 Chemical composition

7.2.1 The chemical composition of ladle samples is to comply with the requirements given in *Table 3.7.1 Chemical composition*.

7.2.2 Consideration will be given to the use of steels whose compositions are outside the scope of *Table 3.7.1 Chemical composition*.

Table 3.7.1 Chemical composition

Type and grade of steel	Chemical composition % (*see* Note)									
	C	Si	Mn	P	S	Cr	Ni	Mo	N	Other
Austenitic										

304 L	0,03	1,0	2,0	0,045	0,03	17,0-20,0	8,0-13,0	-	0,10	-
304 LN	0,03	1,0	2,0	0,045	0,03	17,0-20,0	8,0-12,0	-	0,10-0,22	-
316 L	0,03	1,0	2,0	0,045	0,03	16,0-18,5	10,0-15,0	2,0-3,0	0,10	-
316 LN	0,03	1,0	2,0	0,045	0,03	16,0-18,5	10,0-14,5	2,0-3,0	0,10-0,22	-
317 L	0,03	1,0	2,0	0,045	0,03	18,0-20,0	11,0-15,0	3,0-4,0	0,10	-
317 LN	0,03	1,0	2,0	0,045	0,03	18,0-20,0	12,5-15,0	3,0-4,0	0,10-0,22	-
321	0,08	1,0	2,0	0,045	0,03	17,0-19,0	9,0-12,0	-	0,10	5 x C ≤ Ti ≤ 0,7
347	0,08	1,0	2,0	0,045	0,03	17,0-19,0	9,0-13,0	-	0,10	10 x C ≤ Nb ≤ 1,0
Duplex										
UNS S 31803	0,03	1,0	2,0	0,03	0,02	21,0-23,0	4,5-6,5	2,5-3,5	0,08-0,20	-
UNS S 32750	0,03	0,80	1,2	0,035	0,02	24,0-26,0	6,0-8,0	3,0-5,0	0,24-0,32	Cu 0,50 max.
Note All figures are a maximum value except where a range is shown.										

7.3 Heat treatment

7.3.1 All materials are to be supplied in the solution treated condition.

7.4 Mechanical tests

7.4.1 Tensile test specimens are to be taken in accordance with the appropriate requirements of *Ch 3, 4.4 Mechanical tests* and *Ch 3, 6.4 Mechanical tests 6.4.1*.

7.4.2 For the duplex grades, one set of three Charpy V-notch impact test specimens machined from the longitudinal direction for each tensile test is to be tested at –20°C. The average energy value of the three specimens is to be not less than 41 Joules.

7.4.3 Unless otherwise agreed, impact tests are not required from the austenitic grades of steel given in this Section.

7.4.4 Where standard subsidiary Charpy V-notch test specimens are necessary, *see Ch 2, 2.3 Procedure for testing at ambient temperature 2.3.4*.

7.4.5 The results of all tensile tests are to comply with the requirements of *Table 3.7.2 Mechanical properties for acceptance purposes* or the approved specification.

7.5 Metallographic examination for sigma phase

7.5.1 The microstructure of duplex stainless steel grades listed in *Table 3.7.1 Chemical composition* are to be examined metallographically at x400 magnification to demonstrate that there is no evidence of sigma phase in the observable area. The frequency of testing shall be one test per heat.

7.6 Corrosion tests

7.6.1 For certain specific applications such as storage tanks for chemicals, it may be necessary to demonstrate that the material used is not susceptible to corrosion resulting from precipitation of deleterious phases.

7.6.2 When required, a corrosion test is to be carried out for each tensile test. The material for the corrosion test is to be taken adjacent to that for the tensile test.

7.6.3 Unless otherwise agreed or required for a particular chemical cargo, an intergranular corrosion test for austenitic stainless steels and a pitting corrosion test for duplex stainless steels are to be performed. The testing procedures are given in , *see Ch 2, 9 Corrosion tests* and, for the pitting corrosion test, unless otherwise specified, the test temperatures shall be 20°C for S31803 and 30°C for S32750.

7.6.4 Wherever practical, exposed cut edges should be avoided. However, where any such edges are to remain after fabrication is completed it is to be shown by an appropriate test that the corrosion resistance is adequate for the cargoes expected to be encountered.

7.7 Clad plates

7.7.1 Carbon or carbon-manganese steel plates, clad on one or both surfaces with a suitable grade of austenitic or duplex stainless steel, may be used for the construction of cargo or storage tanks for chemicals.

7.7.2 The carbon or carbon-manganese steel base plates are to comply with the requirements of *Ch 3, 4 Steels for boilers and pressure vessels*, and the austenitic cladding material generally with the requirements of this Section.

7.7.3 The process of manufacture is to be specially approved and may be either by roll cladding or by explosive bonding.

7.7.4 Where the use of clad materials is proposed, the material specification is to be submitted for consideration, together with details of the extent, and the acceptance standards for non-destructive examination.

7.8 Identification of materials

7.8.1 The particulars detailed in *Ch 3, 1.11 Identification of materials* are to be marked on all materials which have been accepted.

Table 3.7.2 Mechanical properties for acceptance purposes

Type and grade of steel	0,2% Proof stress (N/mm^2) minimum	1% Proof stress (N/mm^2) minimum	Tensile strength (N/mm^2) minimum	Elongation on 5,65 $\sqrt{S_0}$ % minimum
Austenitic				
304L	170	210	485	40
304LN	205	245	515	40
316L	170	210	485	40
316LN	205	245	515	40
317L	205	245	515	40
317LN	240	280	550	40
321	205	245	515	40
347	205	245	515	40
Duplex				
UNS S 31803	450	–	620	25
UNS S 32750	550	–	795	15

7.9 Certification of materials

7.9.1 At least two copies of each test certificate are to be provided. They are to be of the type and give the information detailed in *Ch 3, 1.12 Certification of materials* and, where applicable, the results obtained from corrosion tests, and sigma phase assessment. Additionally, the specified maximum carbon equivalent is to be stated. As a minimum, the chemical composition is to include the contents of any grain refining elements used and of the residual elements, as detailed in *Table 3.7.1 Chemical composition*.

■ *Section 8*
Plates with specified through thickness properties

8.1 Scope

8.1.1 Provision is made in this Section for 'Z' grade plate and wide flat material with improved ductility in the through thickness or 'Z' direction, *see Figure 3.8.1 Schematic of testing directions*.The use of this material is recommended for certain types of welded structures (*see Ch 3, 1.2 Steel with guaranteed through thickness properties – 'Z' grade steel*) in order to minimise the possibility of lamellar tearing either during fabrication or erection.

8.1.2 Through thickness properties are characterised by specified values for reduction of area in a through thickness tensile test.

8.1.3 Provision is made for two grades Z25 and Z35. For normal ship applications the Z25 grade is applicable, whilst the Z35 grade is for more severe applications.

8.1.4 This 'Z' grade material is to comply with the requirements of *Ch 3, 2 Normal strength steels for ship and other structural applications*, *Ch 3, 3 Higher strength steels for ship and other structural applications*, *Ch 3, 4 Steels for boilers and pressure vessels*, *Ch 3, 5 Steels for machinery fabrications* and *Ch 3, 6 Ferritic steels for low temperature service* as appropriate, and the additional requirements of this Section.

8.1.5 The test procedure detailed in this Section may also be used to demonstrate that no unacceptable amount of banding of any detrimental phase, such as sigma is present, *see Ch 3, 7.5 Metallographic examination for sigma phase*.

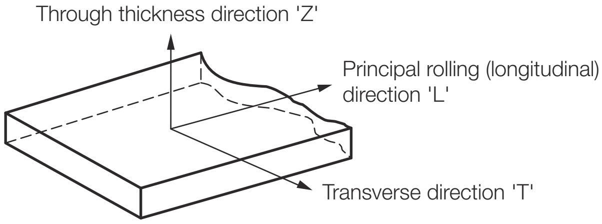


Figure 3.8.1 Schematic of testing directions

8.2 Manufacture

8.2.1 All plates and wide flats are to be manufactured at works which have been approved by LR for this quality of material.

8.2.2 It is recommended that the steel should be efficiently vacuum de-gassed. The sulphur content is not to exceed 0,008 per cent.

8.2.3 Consideration will be given to proposals for alternative methods of improving through thickness properties.

8.3 Test material

8.3.1 Unless otherwise agreed, through thickness tensile tests are only required for plate materials where the thickness exceeds 15 mm for carbon and alloy steels.

8.3.2 For plates and wide flats, one test sample is to be taken close to the longitudinal centreline from one end of each rolled piece representing the batch, *see Table 3.8.1 Batch size dependent on product and sulphur content* and *Figure 3.8.2 Plate and wide flat sampling position*. The test sample must be large enough to accommodate the preparation of 6 specimens. 3 test specimens are to be prepared while the rest of the sample is to be retained for possible retests. The test specimens shall be located in the mid-thickness region of the plate.

Table 3.8.1 Batch size dependent on product and sulphur content

Product	S > 0,005%	S ≤ 0,005%
Plates	Each piece (parent plate)	Maximum 50 t of products of the same cast, thickness and heat treatment

Wide flats of nominal thickness ≤ 25 mm	Maximum 10 t of products of the same cast, thickness and heat treatment	Maximum 50 t of products of the same cast, thickness and heat treatment
Wide flats of nominal thickness > 25 mm	Maximum 20 t of products of the same cast, thickness and heat treatment	Maximum 50 t of products of the same cast, thickness and heat treatment

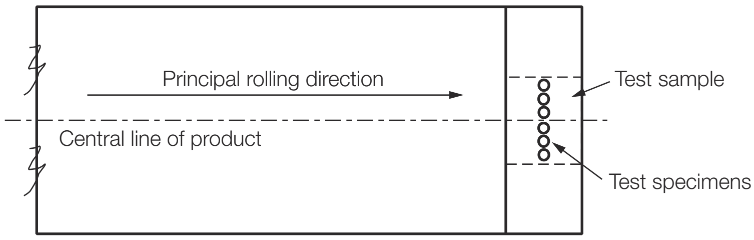


Figure 3.8.2 Plate and wide flat sampling position

8.3.3 The dimensions of the test specimens are to be in accordance with Chapter 2, *Ch 2, 2.1 Dimensions of test specimens 2.1.14*

8.3.4 Alternatively, test sampling may be carried out in accordance with an accepted National or International Standard.

8.4 Mechanical tests

8.4.1 The three through thickness tensile test specimens are to be tested at ambient temperature and for acceptance are to give a minimum average reduction of area value of not less than that shown in *Table 3.8.2 Reduction of area acceptance values*. Only one individual value may be below the minimum average, but should not be less than the minimum individual value shown for the appropriate grade.

Table 3.8.2 Reduction of area acceptance values

Grade	Z25	Z35
Minimum average	25%	35%
Minimum individual	15%	25%

8.4.2 If the average value fails to comply with *Ch 3, 8.4 Mechanical tests 8.4.1*, three additional tests may be made on specimens from the same test sample. The results of these tests are to be added to those previously obtained to form a new average, which for acceptance is to be not less than 25 per cent for grade Z25 or 35 per cent for grade Z35. No individual results in the re-test shall be below 25 per cent for grade Z25 or 35 per cent for grade Z35, *see Figure 3.8.3 Diagram showing acceptance/rejection and retest criteria*.

8.4.3 Where batch testing is permitted, and failure after retest occurs, the tested piece is to be rejected. Each remaining piece in the batch may be individually tested and accepted based on satisfactory results.

8.4.4 If the fracture of a test specimen occurs in the weld or in the heat affected zone the test is to be regarded as invalid and is to be repeated on a new test specimen.

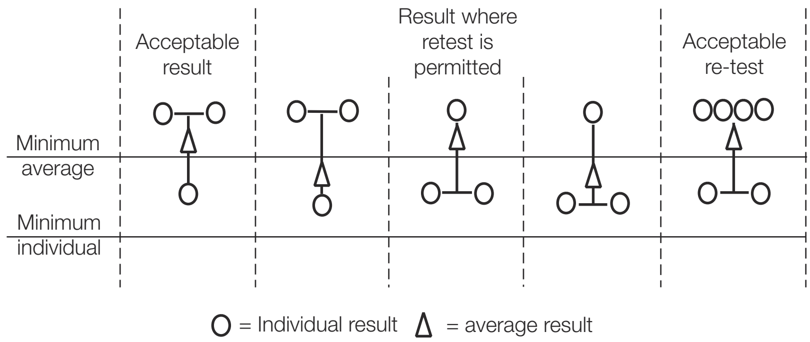


Figure 3.8.3 Diagram showing acceptance/rejection and retest criteria

8.5 Non-destructive examination

8.5.1 All 'Z' grade plates are to be ultrasonically tested in the final supply condition with a probe frequency of 3-5 MHz. The testing is to be performed in accordance with and in compliance with either EN 10160 Level S1/E1 or ASTM A 578 Level C.

8.6 Identification of materials

8.6.1 Products which comply with the requirements of this Section are to have the notation Z25 or Z35 added to the steel grade designation.

8.7 Certification of materials

8.7.1 The following information is required to be included on the certificate in addition to the appropriate steel grade requirements:

(a) Through thickness reduction in area (%), individual results and average.
(b) Steel grade with Z25 or Z35 notation.

8.7.2 Steel grade requirements are to comply with *Ch 3, 1 General requirements*.

■ *Section 9*
Bars for welded chain cables

9.1 Scope

9.1.1 Provision is made in this Section for rolled steel bars intended for the manufacture of three Grades (U1, U2 and U3) of stud link chain cable for the anchoring and mooring of ships and five Grades (R3, R3S, R4, R4S and R5) of offshore mooring cable.

9.1.2 For the ship grades, U1, U2 and U3, approval will permit the supply of bars of the appropriate grades and size to any chain cable manufacturer.

9.1.3 For the offshore grades, R3, R3S, R4, R4S and R5, approval is confined to bar to be supplied to a nominated chain manufacturer and will be given only after successful testing of a completed chain. Separate approvals are required if bar is to be supplied to more than one cable manufacturer. Approval of a higher grade does not cover approval of a lower grade, as all grades must be individually approved.

9.1.4 For all grades, approval is normally given for diameters of bars no greater than those of the bars used in procedure tests.

9.2 Manufacture

9.2.1 All grades of bar material are to be made from killed steel, and, all grades of bar material except for Grade U1 chain cables are to be fine grained. For Grades R4S and R5 the austenite grain size is to be 6 or finer, in accordance with ASTM E112.

9.2.2 The bars are to be made to a specification approved by LR which should include the manufacturing procedure, deoxidation practice, heat treatment and mechanical properties.

9.2.3 The rolling reduction ratio of bars for Grades R3, R3S, R4, R4S and R5 must be at least 5:1.

9.3 Chemical composition

9.3.1 For Grades U1, U2 and U3 the chemical composition should be generally within the limits given in *Table 3.9.1 Chemical composition of killed steel bars*.

9.3.2 For Grades R3, R3S, R4, R4S and R5 the chemical composition is to comply with an approved specification, *see Ch 3, 9.2 Manufacture 9.2.2*.

9.3.3 For Grades R4, R4S and R5 chain cable the steel should contain a minimum of 0,2 per cent molybdenum. The reported composition is to include the contents of antimony, arsenic, tin, copper, nitrogen, aluminium and titanium.

9.3.4 For Grades R4S and R5 the steel used must be vacuum degassed.

9.4 Heat treatment

9.4.1 Unless stipulated otherwise, the bars are to be supplied in the as-rolled condition, but the supplier is to be advised by the chain manufacturer of the heat treatment to be used for the completed chain in order that the mechanical test specimens may be tested in the condition of heat treatment used for the chain.

9.4.2 For Grades U1 and U2, the samples selected from each batch may be tested either in the as-rolled condition, or after heat treatment where the chain is to be used in the heat treated condition, in full cross-section and in a manner simulating the heat treatment applied to the finished cable.

9.4.3 For Grades U3, R3, R3S, R4, R4S and R5 the sample is to be tested after heat treatment as detailed in *Ch 3, 9.4 Heat treatment 9.4.2*.

Table 3.9.1 Chemical composition of killed steel bars

Grade	Chemical composition %												
	C max.	Si	Mn	P max.	S max.	Al	Nb max.	V max.	N max.	Cr max.	Cu max.	Ni max.	Mo max.
U1	0,20	0,15–0,35	0,40 min.	0,04	0,04	—	—	—	—	—	—	—	—
U2	0,24	0,15–0,55	1,60 max.	0,035	0,035	0,02 min. *see* Note 1	—	—	—	—	—	—	—
U3	0,33	0,15–0,35	1,90 max	0,04	0,04	0,065 max. *see* Note 2	0,05 *see* Note 2	0,10 *see* Note 2	0,015	0,25	0,35	0,40	0,08

Note 1. Aluminium may be partly replaced by other grain refining elements.

Note 2. To obtain fine grain steel, at least one of these grain refining elements must be present in sufficient amount.

9.5 Embrittlement tests

9.5.1 For Grades R3, R3S, R4, R4S and R5 the bar manufacturer is to provide evidence that the material is not susceptible to strain ageing or to temper brittleness under the conditions of manufacture of the chain. The results of the relevant tests are to be reported to LR at the approval stage. Approval will be restricted to the specified steel composition and if later this is altered then re-approval will be required. Temper brittleness testing may be waived if the chain is to be quenched after tempering.

9.5.2 Each heat of steel bars of grades R3S, R4, R4S and R5 is to be tested for hydrogen embrittlement (*see Ch 2, 5.3 Hydrogen embrittlement tests*). In the case of continuous casting, test samples representing both the beginning and the end of the heat are to be taken. In the case of ingot casting, test samples representing two different ingots are to be taken.

9.5.3 Each sample is to be heat treated in a manner simulating the heat treatment of the finished chain. From each sample two specimens are to be prepared from the mid-diameter of the bar and tested in accordance with *Ch 2, 5.3 Hydrogen embrittlement tests*.

9.5.4 The ratio Z_1/Z_2 is to be greater than or equal to 0,85, where Z_1 is the reduction in area without baking and Z_2 the reduction in area after baking.

9.5.5 If the requirement is not met, the material is to be subjected to a hydrogen degassing treatment which is subject to approval by LR. Further tests are to be performed after degassing.

9.6 Mechanical tests

9.6.1 Bars of the same nominal diameter are to be presented for test in batches of 50 tonnes or fraction thereof from the same cast. A suitable length from one bar in each batch is to be selected for test purposes. Test pieces are to be taken from the positions as shown in *Figure 3.9.1 Sampling of steel bars*.

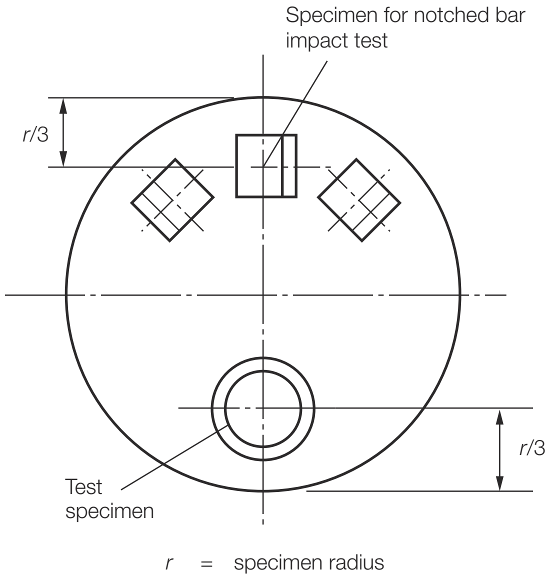


Figure 3.9.1 Sampling of steel bars

9.6.2 For all grades, one tensile test is to be taken from each sample length selected. Additionally, for Grades U3, R3, R3S, R4, R4S and R5 material, one set of three Charpy V-notch impact test specimens is to be prepared. Impact tests are also required for Grade U2 when the chain is to be supplied in as-welded condition.

9.6.3 The results of all tensile and, where applicable, impact tests are to be in accordance with the appropriate requirements of *Table 3.9.2 Mechanical properties*.

Table 3.9.2 Mechanical properties

Grade	Yield stress N/mm² minimum	Tensile strength N/mm²	Elongation on 5,65 $\sqrt{S_0}$ % minimum	Reduction of area % minimum	Charpy V-notch impact tests		
					Test temperature °C	Average energy J minimum	Average energy flash weld J minimum
U1	—	370–490	25	—	—	—	—
U2	295	490–690	22	—	0 (*see* Note 1)	27	—
U3	410	690 minimum	17	40	0	60	—
					–20 (*see* Note 2)	35	—
R3	410 (*see* Note 3)	690 minimum (*see* Note 3)	17	50	0	60	50

					–20 (*see* Note 2)	40	30
R3S	490 (*see* Note 3)	770 minimum (*see* Note 3)	15	50	0	65	53
					–20) (*see* Note 2)	45	33
R4	580 (*see* Note 3)	860 minimum (*see* Note 3)	12	50	–20	50	36
Grade R4S (*see* Note 4)	700 (*see* Note 3)	960 minimum (*see* Note 3)	12	50	–20	56	40
Grade R5 (*see* Note 4)	760(*see* Note 3)	1000 minimum (*see* Note 3)	12	50	–20	58	42

Note 1. Impact tests may be waived when the chain cable is to be supplied in one of the heat treated conditions given in *Table 10.2.3 Condition of supply and scope of mechanical tests for finished chain cables and fittings*.

Note 2. Testing may be carried out at either 0°C or –20°C, at the option of LR.

Note 3. The ratio of yield strength to tensile strength should not exceed 0,92.

Note 4. The maximum hardness for R4S is to be HB330, and for R5 is to be HB340.

9.6.4 Failure to meet the requirements will result in the rejection of a batch of material, unless it is clearly attributed to improper simulated heat treatment. This is to be confirmed to be to the satisfaction of LR, and further heat treatment and testing will be required prior to acceptance.

9.7 Structure and hardenability tests

9.7.1 For Grades R4S and R5, the following tests are to be carried out on each heat:

(a) Assessment and quantification of the level of non-metallic micro inclusion. These must be acceptable for the final product.
(b) Macro etching on a representative sample, in accordance with ASTM E381 or equivalent. This must be free from any injurious segregation or porosity.
(c) Jominy hardenability tests in accordance with ASTM A255 or equivalent.

9.8 Dimensional tolerances

9.8.1 The tolerances on diameter and ovality of the bar are to be in accordance with *Table 3.9.3 Dimensional tolerance of bar stock*.

Table 3.9.3 Dimensional tolerance of bar stock

Nominal diameter mm	Tolerance on diameter mm	Tolerance on roundness ($d_{max}– d_{min}$) mm
≤20	–0/+1,0	0,60
>20 ≤25	–0/+1,0	0,60
>26 ≤35	–0/+1,2	0,80
>36 ≤50	–0/+1,6	1,10
>51 ≤80	–0/+2,0	1,50
>81 ≤100	–0/+2,6	1,95
>101 ≤120	–0/+3,0	2,25

>121 ≤160	–0/+4,0	3,00
>161 ≤210	–0/+5,0	4,00

9.9 Non-destructive examination

9.9.1 For the grades U1, U2 and U3 all bars are to be free from internal and surface defects that might impair proper workability, use and strength. Subject to agreement by the Surveyor, surface defects may be removed by grinding provided the acceptable tolerances are not exceeded.

9.9.2 For the R3, R3S, R4, R4S and R5 grades all bars are to be inspected by a magnetic particle or eddy current method and are also to be subjected to ultrasonic examination.

9.9.3 All non-destructive examination is to be carried out in accordance with approved procedures, in accordance with *Ch 1, 5 Non-destructive examination*.

9.9.4 All non-destructive examination operators are to be qualified in the method of non-destructive examination to a minimum of Level II in accordance with a recognised standard.

9.9.5 The bars are to be free from pipes, cracks, flakes, and injurious surface defects such as seams, laps, and rolled in mill scale. Longitudinal discontinuities may be removed by blending to a smooth contour provided that their depth is not greater than 1 per cent of the bar diameter, and that the required diameter tolerances are not compromised. The contour radiuses are to be a minimum of four times the excavation depth.

9.9.6 The frequency of non-destructive testing may be reduced at the discretion of LR, provided statistical evidence is available that the required quality is achieved consistently.

9.10 Identification

9.10.1 Each bar is to be identified in accordance with *Ch 3, 1.11 Identification of materials* and, in addition, is to be marked with the appropriate grade of chain cable.

9.11 Certification of materials

9.11.1 Each consignment of bars is to be accompanied by a certificate of a type and in accordance with *Ch 3, 1.12 Certification of materials* but with the addition of the grade of chain cable, the rolling reduction ratio, the results of the hydrogen embrittlement, micro inclusion, macro etch and hardenability tests, where required by each grade.

■ *Section 10*
High strength quenched and tempered steels for welded structures

10.1 Scope

10.1.1 Provision is made in this Section for weldable high strength quenched and tempered steel plates and wide flats up to 70 mm thick. However, special consideration will be given to thicknesses up to 50 mm supplied in the TM rolled condition.

10.1.2 Plates and wide flats exceeding 70 mm in thickness as well as other product forms may also be supplied in accordance with the requirements of this Section provided that the prior agreement of LR is obtained.

10.1.3 The steels may be supplied in six strength levels with minimum yield stresses of 420, 460, 500, 550, 620 and 690 N/mm^2 respectively.

10.1.4 Each strength level is sub-divided into four grades AH, DH, EH and FH, differing essentially in the required levels of notch toughness.

10.1.5 For the designation to fully identify a steel and its properties, the appropriate grade letter should precede the strength level number, e.g. EH 42.

10.1.6 Steels differing in strength level, mechanical properties and chemical composition from those detailed in this Section may be supplied, subject to special approval from LR. Such steels are to have the letter `S' after the agreed identification mark.

10.2 Manufacture and chemical composition

10.2.1 The steels are to be fully killed and fine grain treated.

10.2.2 The chemical composition is to comply with the requirements of the approved manufacturing specification and the limits set in *Table 3.10.1 Chemical composition*.

Table 3.10.1 Chemical composition

Grade	AH	DH EH	FH
Carbon % max	0,21	0,20	0,18
Manganese % max	1,70	1,70	1,60
Silicon % max	0,55	0,55	0,55
Phosphorus % max	0,035	0,030	0,025
Sulphur % max	0,035	0,030	0,025
Nitrogen % max	0,020	0,020	0,020
Grain refining elements (*see* Note 1)			
Aluminium (acid soluble) % min (*see* Note 2)	0,015		
Niobium %	0,02—0,05		
Vanadium %	0,03—0,10		
Titanium % max	0,02		
Total (Nb + V + Ti) % max	0,12		

Note 1. The steel is to contain aluminium, niobium, vanadium or other suitable grain refining elements, either singly or in any combination. When used singly, the content is to be within the limits given in the Table. When used in combination, these limits are not applicable but the proportions of the grain refining elements are to be in accordance with the approved manufacturing specification.

Note 2. The total aluminium content may be determined instead of the acid soluble content. In such cases the total aluminium content is not to be less than 0,020%.

Note 3. Alloying elements and residual elements other than those listed in the Table (e.g. Ni, Cr, Cu, Mo and B) are to be included in the approved manufacturing specification.

10.2.3 The cold cracking susceptibility, P_{cm}, may be used as an alternative to the carbon equivalent for evaluating weldability. It is to be calculated from the ladle analysis using the following formula:

$$P_{\mathrm{cm}} = \mathrm{C} + \frac{\mathrm{Si}}{30} + \frac{\mathrm{Mn} + \mathrm{Cr} + \mathrm{Cu}}{20} + \frac{\mathrm{Ni}}{60} + \frac{\mathrm{Mo}}{15} + \frac{\mathrm{V}}{10} + 5\mathrm{B}$$

The maximum allowable P_{cm} is to be agreed with LR and is to be included in the approved manufacturing specification.

10.3 Mechanical properties

10.3.1 At least one tensile test piece and one set of three Charpy V-notch impact tests specimens are to be taken from each piece as heat treated.

10.3.2 For continuously heat treated products, one tensile test piece and a set of three impact test specimens are to be taken from each plate as heat treated.

10.3.3 For plates and wide flats with widths exceeding 600 mm, the tensile and impact test specimens are to be taken with their axes transverse to the final direction of rolling. For other products, the impact test specimens are to be taken in the longitudinal direction but the tensile test specimens may be taken in either the longitudinal or transverse direction as agreed with LR.

10.3.4 The results of all tests are to comply with the appropriate requirements of *Table 3.10.2 Mechanical properties for acceptance purposes*.

10.3.5 Where standard subsidiary impact test specimens are necessary, *see Ch 2, 2.3 Procedure for testing at ambient temperature 2.3.4*.

10.4 Identification of materials

10.4.1 The particulars detailed in *Ch 3, 1.11 Identification of materials* are to be marked on each piece which has been accepted and, for ease of recognition, are to be encircled or otherwise marked with paint.

10.5 Certification of materials

10.5.1 At least two copies of each test certificate are to be provided. They are to be of the type and give the information detailed in *Ch 3, 1.12 Certification of materials* and, additionally, are to state the specified maximum carbon equivalent. As a minimum, chemical composition is to include the contents of any grain refining elements used and of the residual elements as detailed in *Table 3.10.1 Chemical composition*.

Table 3.10.2 Mechanical properties for acceptance purposes

Grade	Yield stress N/mm^2 min. (*see* Note 1)	Tensile strength N/mm^2	Elongation on $5,65\sqrt{S_o}$ % minimum (*see*Note 2)		Charpy V-notch impact tests (*see* Note 4)		
					Test temperature °C	Average energyJ minimum	
			Transverse	Longitudinal		Transverse	Longitudinal
AH42 DH42 EH42 FH42	420	530– 680	18	20	0 –20 –40 –60	28	42
AH46 DH46 EH46 FH46	460	570– 720	17	19	0 –20 –40 –60	31	46
AH50 DH50 EH50 FH50	500	610– 770	16	18	0 –20 –40 –60	33	50
AH55 DH55 EH55 FH55	550	670– 830	16	18	0 –20 –40 –60	37	55
AH62 DH62 EH62 FH62	620	720– 890	15	17	0 –20 –40 –60	41	62
AH69 DH69 EH69 FH69	690	770– 940	14	16	0 –20 –40 –60	46	69

Note 1. Where a distinct yield stress indication is not obtainable during tensile testing the 0,2% proof stress is applicable.

Note 2. For full thickness tensile test specimens with a width of 25 mm and a gauge length of 200 mm (*see* Fig. 2.2.4 in Chapter 2) the minimum elongation is to be:

Thickness mm		≤ 10	> 10 ≤ 15	> 15 ≤ 20	> 20 ≤ 25	> 25 ≤ 40	> 40 ≤ 50	> 50 ≤ 70
Strength levels								
Elongation %	42	11	13	14	15	16	17	18
	46	11	12	13	14	15	16	17
	50 and 55	10	11	12	13	14	16	16
	62	9	11	12	12	13	14	15
	69	9	10	11	11	12	13	14

These values apply to transverse specimens. Where the use of longitudinal specimens has been agreed, the values are to be increased by 2%.

Note 3. The ratio of yield strength to tensile strength should not exceed 0,94.

Note 4. Impact tests are not required on thicknesses less than 6 mm.

Contents

■ *Section 1*
General requirements

1.1 Scope

1.1.1 This Section gives the general requirements for steel castings intended for use in the construction of ships, other marine structures, machinery, boilers, pressure vessels and piping systems.

1.1.2 Where required by the relevant Rules dealing with design and construction, castings are to be manufactured and tested in accordance with Chapters*Ch 1 General Requirements* and *Ch 2 Testing Procedures for Metallic Materials*, together with the general requirements given in this Section and the appropriate specific requirements given in Sections *Ch 4, 2 Castings for ship and other structural applications*.

1.1.3 As an alternative to *Ch 4, 1.1 Scope 1.1.2*, castings which comply with National or proprietary specifications may be accepted provided that these specifications give reasonable equivalence to the requirements of this Chapter or alternatively are approved for a specific application. Generally, survey and certification are to be carried out in accordance with the requirements of *Ch 1 General Requirements*.

1.1.4 Where small castings are produced in large quantities, or where castings of the same type are produced in regular quantities, alternative survey procedures, in accordance with *Ch 1, 2.4 Materials Quality Scheme*, may be adopted.

1.2 Manufacture

1.2.1 Castings are to be made at foundries approved by LR. The steel used is to be manufactured by a process approved by Lloyd's Register (hereinafter referred as 'LR').

1.2.2 All flame cutting, scarfing or arc-air gouging to remove surplus metal is to be undertaken in accordance with recognised good practice and is to be carried out before the final heat treatment. Preheating is to be employed where necessitated by the chemical composition and/or thickness of the casting. The affected areas are to be either machined or ground smooth for a depth of about 2 mm unless it has been shown that the material has not been damaged by the cutting process. Special examination will be required to find any cracking in way of the cut surfaces.

1.2.3 Where two or more castings are joined by welding to form a composite item, details of the proposed welding procedure are to be submitted for approval. Welding approval procedure tests will be required, *see also* the requirements of *Ch 4, 1.9 Rectification and dressing of castings*.

1.3 Quality of castings

1.3.1 All castings are to be free from surface or internal defects which would be prejudicial to their proper application in service. The surface finish is to be in accordance with good practice and any specific requirements of the approved specification.

1.3.2 The surfaces are not to be hammered, peened or treated in any way which may obscure defects.

1.3.3 The locations of all chaplets are to be noted and to be subject to close visual inspection (and when necessary ultrasonic examination) to ensure complete fusion.

1.4 Chemical composition

1.4.1 All castings are to be made from killed steel. The chemical composition of the ladle sample is to be within the limits given in the relevant Section of this Chapter. Where general overall limits are specified, the chemical composition is to be appropriate for the type of steel, dimensions and required mechanical properties of the castings.

1.4.2 Except where otherwise specified, suitable grain refining elements may be used at the discretion of the manufacturer. The content of such elements is to be reported in the ladle analysis.

1.5 Heat treatment

1.5.1 All castings are to be heat treated in accordance with the requirements given in the relevant Section of this Chapter.

1.5.2 Heat treatment is to be carried out in a properly constructed furnace which is efficiently maintained and has adequate means of temperature control. The furnace dimensions are to be such as to allow the steel castings to be uniformly heated to the necessary temperature. Sufficient thermocouples are to be connected to the steel castings to show that their temperature is adequately uniform and the temperatures are to be recorded throughout the heat treatment. Alternative procedures are to be approved by LR, Materials and NDE department. Copies of these records are to be presented to the Surveyor together with a sketch showing the positions at which the temperature measurements were carried out. The records are to identify the furnace that was used and give details of the individual steel castings, the heat treatment temperature and time at temperature and the date. The Surveyor is to examine the charts and confirm the details on the certificate. In the case of very large components which require heat treatment, alternative methods will be specially considered.

1.5.3 If a casting is locally reheated, or any straightening operation is performed after the final heat treatment, a subsequent stress relieving heat treatment may be required in order to avoid the possibility of harmful residual stresses.

1.6 Test material and test specimens

1.6.1 Test material sufficient for the tests specified in Sections *Ch 4, 2 Castings for ship and other structural applications* and for possible re-test purposes is to be provided for each casting. The test samples are to be either integrally cast or gated to the casting and are to have a thickness of not less than 30 mm.

1.6.2 The test samples are not to be detached from the casting until the heat treatment specified in *Ch 4, 1.5 Heat treatment 1.5.1* has been completed and they have been properly identified.

1.6.3 As an alternative to *Ch 4, 1.6 Test material and test specimens 1.6.1* and *Ch 4, 1.6 Test material and test specimens 1.6.2*, where a number of small castings of about the same size, each of which is under 1000 kg in mass, are made from one cast and heat treated in the same furnace charge, a batch testing procedure may be adopted, using separately cast test samples of suitable dimensions. The test samples are to be properly identified and heat treated together with the castings which they represent. At least one test sample is to be provided for each batch of castings.

1.6.4 The test specimens are to be prepared in accordance with the requirements of *Ch 2 Testing Procedures for Metallic Materials*. Tensile test specimens are to have a cross-sectional area of not less than 150 mm^2.

1.6.5 Re-test procedures are to be in accordance with *Ch 2, 1.4 Re-testing procedures*.

1.7 Visual and non-destructive examination

1.7.1 This Section gives the general requirements for non-destructive examination of steel castings. As an alternative, castings may be examined in accordance with a National Specification, provided it gives reasonable equivalence to these Rules.

1.7.2 All castings are to be cleaned and adequately prepared for inspection. Suitable methods include pickling, caustic cleaning, wire brushing, local grinding, shot or sand blasting.

1.7.3 The surfaces are not to be hammered, peened or treated in any way which may obscure defects.

1.7.4 Unless otherwise agreed, the accuracy and verification of dimensions are the responsibility of the manufacturer.

1.7.5 All castings are to be presented to the Surveyor for visual examination. Where applicable, this is to include the examination of internal surfaces. Castings are to be subject to magnetic particle examination or dye penetrant inspection (for austenitic stainless steel castings, *see Ch 4, 8 Stainless steel castings*) in accordance with *Ch 4, 1.7 Visual and non-destructive examination 1.7.9*, unless more specific requirements for non-destructive examination are included in subsequent Sections of this Chapter, other parts of the Rules or the agreed specification.

1.7.6 Where specified or required by the Rules non-destructive examination is to be carried out before acceptance. All tests are to be in accordance with the requirements of *Ch 1, 5 Non-destructive examination*.

1.7.7 The manufacturer is to provide the Surveyor with a signed report confirming that non-destructive examination has been carried out and that such inspection has not revealed any significant defects.

1.7.8 Where magnetic particle examination is specified or required, this is to be carried out using a suspension of magnetic particles in a suitable fluid. The dry powder method is not acceptable for the final inspection. Prods are not permitted on finished machined surfaces.

1.7.9 Where required, magnetic particle or dye penetrant testing is to be carried out by the manufacturer whenever appropriate and also when the castings are in the finished condition. The tests are to be made in the presence of the Surveyor unless otherwise specially agreed. The castings are to be examined in the following areas:

(a) At all accessible fillets and changes of section.
(b) At positions where surplus metal has been removed by flame cutting, scarfing or arc-air gouging.
(c) In way of fabrication weld preparations, for a distance not less than 50 mm from the edge.
(d) In way of welds.
(e) In way of chaplets.
(f) At other positions agreed with the Surveyor to include areas which may be subjected to high stress in service.

1.7.10 Where required by subsequent Sections or by the agreed specification, ultrasonic examination is to be carried out by the manufacturer, but Surveyors may request to be present in order to verify that the examination is carried out in accordance with the agreed procedure. This examination is to be carried out in the following areas:

(a) At positions which may be subjected to high stresses in service, as agreed with the Surveyor.
(b) In way of fabrication weld preparations, for a distance not less than 50 mm from the edge.
(c) At positions where subsequent machining may expose filamentary shrinkage or other defects (e.g. bolt holes, bearing bores).
(d) In way of welding.
(e) In way of riser positions.
(f) At positions where experience shows that significant internal defects may occur: these are to be agreed between the manufacturer and the Surveyor.

1.7.11 Radiographic examination, where required, is to be carried out by the manufacturer in areas generally as indicated for ultrasonic examination in *Ch 4, 1.7 Visual and non-destructive examination 1.7.10*. All radiographs are to be submitted to the Surveyor for examination and acceptance. The radiographic technique and acceptance standards are to be to the satisfaction of the Surveyor and in accordance with any requirements of the approved specification.

1.7.12 In the event of any casting proving to be defective during subsequent machining or testing it is to be rejected notwithstanding any previous certification.

1.7.13 The general acceptance criteria given in *Ch 4, 2.5 Non-destructive examination 2.5.2* are to be applied where no specific acceptance criteria are stated in the subsequent Sections of this Chapter.

1.8 Pressure testing

1.8.1 Where required by the relevant Rules, castings are to be pressure tested in the final machined condition before final acceptance. These tests are to be carried out in the presence of the Surveyors and are to be to their satisfaction.

1.9 Rectification and dressing of castings

1.9.1 When unacceptable defects are found in a casting, these are to be removed by machining or chipping. Flame-scarfing or arc-air gouging may also be used provided that preheating is employed when necessary and that the surfaces of the resulting excavation are subsequently ground smooth. Complete elimination of the defective material is to be proven by adequate non-destructive examination. Shallow grooves or excavations resulting from the removal of defects may, at the discretion of the Surveyor, be accepted provided that they will cause no appreciable reduction in the strength of the castings and that they are suitably blended by grinding. Complete elimination of the defective material is to be verified by magnetic particle or dye penetrant testing.

1.9.2 Where flame scarfing or arc-air gouging is used, the requirements detailed in *Ch 4, 1.2 Manufacture 1.2.2* are to apply.

1.9.3 Grinding wheels for use on austenitic stainless steels are to be of an iron-free type and shall have been used only on stainless steels.

1.9.4 All proposals to repair a defective casting by welding are to be submitted to the Surveyor before this work is commenced. The Surveyor is to satisfy himself that the number, position and size of the defects are such that the casting can be effectively repaired.

1.9.5 A statement and/or sketch detailing the extent and position of all welds is to be prepared by the manufacturer. Copies of these sketches are to be submitted to LR, and copies are to be attached to the certificates for the castings.

1.9.6 All welding is to be carried out by an approved welder and in accordance with an approved welding procedure which includes the features referred to in *Ch 4, 1.9 Rectification and dressing of castings 1.9.6*.

1.9.7 Where welding is required, a grain refining heat treatment is to be given to the whole casting prior to carrying out welding unless agreed otherwise with the Surveyor. Grain refining heat treatment requires heating above the upper critical temperature.

1.9.8 Any excavations are to be of suitable shape to allow good access for welding and, after final preparation for welding, are to be re-examined by suitable non-destructive testing methods to ensure that all defective material has been eliminated.

1.9.9 All castings in alloy steels other than austenitic and duplex stainless steels are to be suitably preheated prior to welding. Castings in carbon-manganese steels may also be required to be preheated, depending on their chemical composition, the dimensions, configuration and positions of the welds.

1.9.10 Welding is to be carried out under cover, in positions free from draughts and adverse weather conditions. As far as possible, all welding is to be carried out in the downhand (flat) position.

1.9.11 The welding consumables used are to be of an appropriate composition, giving a weld deposit with mechanical properties similar and in no way inferior to those of the parent castings. The use of low hydrogen type welding consumables is preferred. Welding procedure tests are to be carried out by the manufacturer to demonstrate that satisfactory mechanical properties can be obtained after heat treatment as detailed in *Ch 4, 1.9 Rectification and dressing of castings 1.9.12*, and the results of these tests are to be presented to the Surveyor.

1.9.12 After welding is completed, the castings are to be given the heat treatment specified in Sections *Ch 4, 2 Castings for ship and other structural applications*, or a stress relieving heat treatment at a temperature of not less than 550°C. The type of heat treatment required will be dependent on the chemical composition of the casting and the dimensions, positions and nature of the repairs.

1.9.13 Special consideration may be given to a local stress relieving heat treatment where both the welded area is small and machining of the casting has reached an advanced stage, but prior agreement is to be obtained from LR in writing. The welding procedure is to be such that residual stresses are minimised.

1.9.14 On completion of heat treatment, all welds and adjacent material are to be ground smooth and examined by magnetic particle, or liquid penetrant testing, ultrasonic or radiographic examination. The Surveyor is to attend at these inspections, to witness the results of magnetic particle or liquid penetrant examination and to examine any radiographs. Satisfactory results are to be obtained from all forms of non-destructive examination used. The acceptance criteria for the NDE of welds are to be in accordance with subsequent Sections of this Chapter or where these do not exist, *Table 13.2.4 Acceptance criteria for visual testing, magnetic particle and liquid penetrant testing* in Chapter 13, as appropriate.

1.9.15 Where no welding has been made on a casting, the manufacturer is to provide the Surveyor with a written statement that this is the case.

1.9.16 The foundry is to maintain full records detailing the weld procedure, heat treatment and the extent and location of all welds made to each casting. These records are to be available for review by the Surveyor, and copies of individual records are to be supplied to the Surveyor on request.

1.9.17 For rectification of defective steel castings for crankshafts, *see Ch 4, 4.7 Rectification of defective castings*.

1.10 Identification of castings

1.10.1 The manufacturer is to adopt a system of identification, which will enable all finished castings to be traced to the original cast, and the Surveyor is to be given full facilities to trace the castings when required.

1.10.2 Before acceptance, all castings which have been tested and inspected with satisfactory results are to be clearly marked by the manufacturer with the following particulars:

(a) Identification number, cast number or other marking which will enable the full history of the casting to be traced.
(b) Manufacturer’s name or trade mark.
(c) LR or Lloyd's Register and the abbreviated name of LR's local office.

(d) Personal stamp of Surveyor responsible for inspection.
(e) Test pressure, where applicable.
(f) Date of final inspection.

1.10.3 Where small castings are manufactured in large numbers, modified arrangements for identification may be specially agreed with the Surveyor.

1.11 Certification of materials

1.11.1 A LR certificate is to be issued, *see Ch 1, 3.1 General*.

1.11.2 The manufacturer is to provide the Surveyor with a written statement giving the following particulars for each casting or batch of castings which has been accepted:

(a) Purchaser's name and order number.
(b) Description of castings and steel grade.
(c) Identification number.
(d) Steel-making process, cast number, chemical analysis of ladle samples and, in the case of the Special grade (*see Ch 4, 2 Castings for ship and other structural applications*), the chemical analysis of the product or test bar.
(e) General details of heat treatment including the temperature and time at temperature.
(f) Results of mechanical tests.
(g) Test pressure, where applicable.

1.11.3 Where applicable, the manufacturer is to provide a signed report regarding non-destructive examination as required by *Ch 4, 1.7 Visual and non-destructive examination 1.7.7* together with a statement and/or a sketch detailing the extent and position of all weld repairs made to each casting as required by *Ch 4, 1.9 Rectification and dressing of castings 1.9.5* or the statement detailed in *Ch 4, 1.9 Rectification and dressing of castings 1.9.15*.

■ *Section 2*
Castings for ship and other structural applications

2.1 Scope

2.1.1 The requirements for carbon-manganese steel castings, intended for ship and other structural applications where the design and acceptance tests are related to mechanical properties at ambient temperature, are given in this Section.

2.1.2 Provision is made for two quality grades, Normal and Special.

2.1.3 Where it is proposed to use carbon-manganese steels of higher specified minimum tensile strength than required by *Ch 4, 2.4 Mechanical tests 2.4.3*, or alloy steels, particulars of the chemical composition, mechanical properties and heat treatment are to be submitted for approval.

2.2 Chemical composition

2.2.1 The chemical composition of ladle samples is to comply with *Table 4.2.1 Chemical composition*.

Table 4.2.1 Chemical composition

Quality grade	Normal	Special (*see* Note 3)
Carbon	0,23% max.	0,23% max.
Silicon	0,60% max.	0,60% max.
Manganese	0,70 – 1,60%	0,70 – 1,60%
Sulphur	0,040% max.	0,035% max.
Phosphorus	0,040% max.	0,035% max.

Aluminium - (acid soluble)	–	0,015 – 0,080% (*see* Notes 1 and 2)
Residual elements:		
Copper	0,30% max.	0,30% max.
Chromium	0,30% max.	0,30% max.
Nickel	0,40% max.	0,40% max.
Molybdenum	0,15% max.	0,15% max.
Total	0,80% max.	0,80% max.
Note 1. The total aluminium content may be determined instead of the acid soluble content, in which case the total aluminium content is to be 0,020 – 0,10%. Note 2. Grain refining elements other than aluminium may be used subject to special agreement with LR. Note 3. For the Special grade, the nitrogen content is to be determined.		

2.2.2 For the Special grade, the product of the aluminium and nitrogen contents is to comply with the following formula:

$$(\%\,\mathrm{Al}_{\mathrm{acid\ sol}} \times \%\,\mathrm{N})10^5 \leq 60$$

2.2.3 For the Special grade, a check chemical analysis on the product or a test bar is mandatory. The check analysis on the product or test bar is to comply with the requirements of *Table 4.2.1 Chemical composition*.

2.3 Heat treatment

2.3.1 Castings are to be supplied:

(a) fully annealed; or
(b) normalised; or
(c) normalised and tempered at a temperature of not less than 550°C; or
(d) quenched and tempered at a temperature of not less than 550°C.

2.3.2 For larger castings where a coarser microstructure may be present in heavier thickness, a double austenising heat treatment may be required to ensure adequate grain refinement. A coarse microstructure will be indicated by an increased attenuation of approximately 30 dB/m at 2 MHz during ultrasonic examination.

2.3.3 Following weld repair and or the attachment of handling brackets, all castings are to be subject to post weld heat treatment at a temperature of not less than 550°C before delivery.

2.4 Mechanical tests

2.4.1 At least one tensile test is to be made on material representing each casting or batch of castings.

2.4.2 Where the casting is of complex design, or where the finished mass exceeds 10 tonnes, two test samples are to be provided. Where large castings are made from two or more casts which are not mixed in a ladle prior to pouring, two or more test samples are required corresponding to the number of casts involved. These are to be integrally cast at locations as widely separated as possible.

2.4.3 The results of these tests are to comply with the following requirements:

Yield stress	200 N/mm^2 min.
Tensile strength	400 N/mm^2 min.

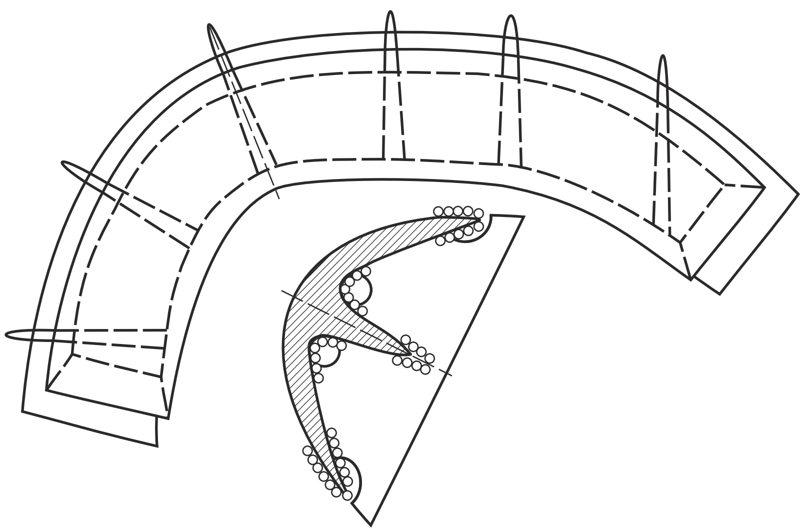
Elongation on 5,65 $\sqrt{S_o}$	25% min.
Reduction of area	40% min.

2.4.4 A set of three Charpy V-notch impact test specimens is to be provided with each casting in the Special grade. These may be taken from a small extension of the thickest part of the casting or from a block cast integrally with the casting and having dimensions representative of the largest section thickness of the casting. These are to be tested in accordance with *Ch 2 Testing Procedures for Metallic Materials* and are to have an average energy of not less than 27J at 0°C.

2.5 Non-destructive examination

2.5.1 Castings used in ship construction for the sternframe, rudder and propeller shaft supports are to be examined by ultrasonic and magnetic particle methods in accordance with *Ch 4, 1.7 Visual and non-destructive examination*. The type and extent of non-destructive examination of castings for other structural applications are to be specially agreed by the Surveyor.

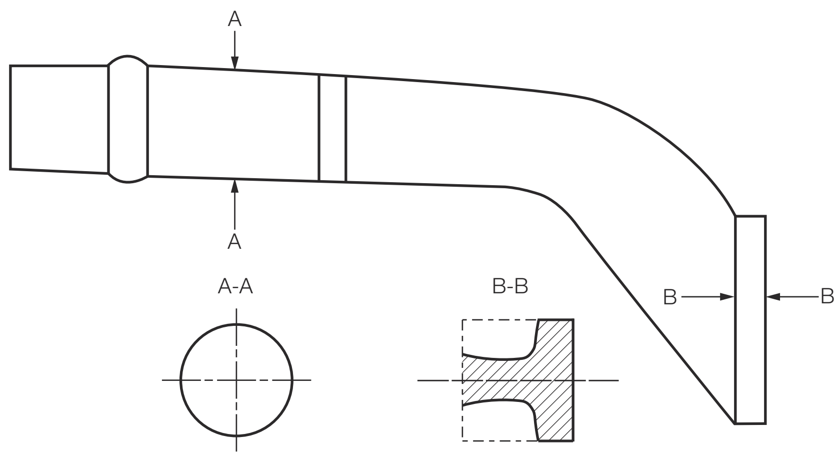
2.5.2 The extent and methods of non-destructive examination to be applied to typical hull steel castings are shown in *Figure 4.2.1 Extent of non-destructive evaluation for stern frame castings* in addition to the areas specified in *Ch 4, 1.7 Visual and non-destructive examination 1.7.9* and *Ch 4, 1.7 Visual and non-destructive examination 1.7.10*.



Location of non-destructive examination

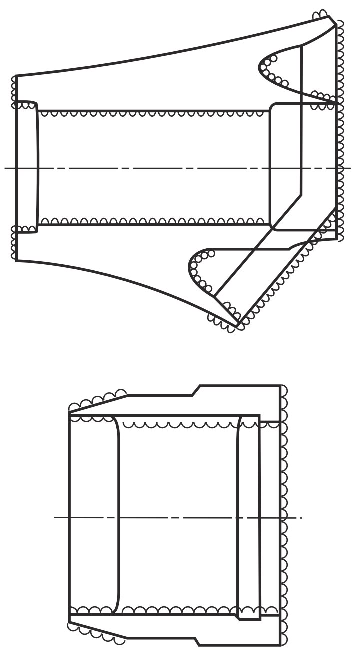
1. All surfaces: Visual examination
2. Location indicated with (ooo): Magnetic particle and Ultrasonic testing

Figure 4.2.1 Extent of non-destructive evaluation for stern frame castings



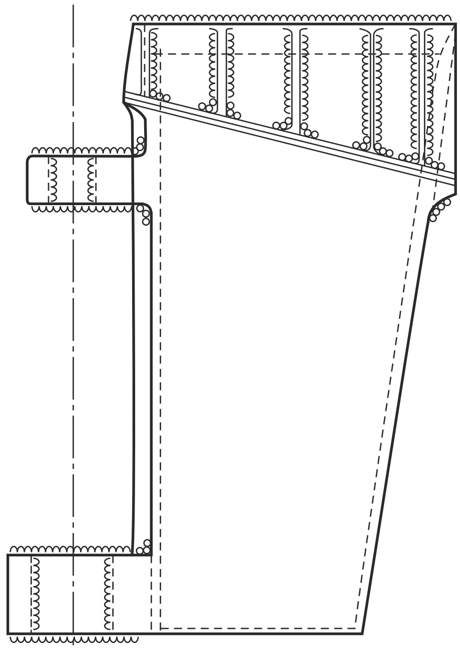
Location of non-destructive examination
All surfaces: Visual examination
Magnetic particle and ultrasonic testing

Figure 4.2.2 Extent of non-destructive evaluation for rudder stock castings



Location of non-destructive examination
1. All surfaces: Visual examination
2. Location indicated with (ooo): Magnetic particle and ultrasonic testing
3. Location indicated with (⌒⌒⌒): Ultrasonic testing

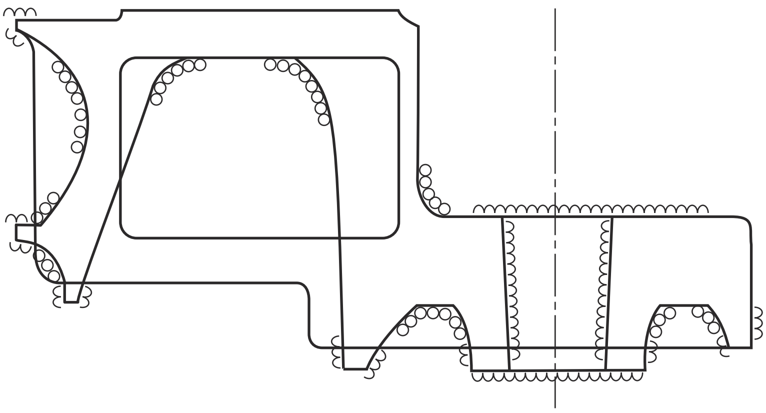
Figure 4.2.3 Extent of non-destructive evaluation for stern boss castings



Location of non-destructive examination

1. All surfaces: Visual examination
2. Location indicated with (OOO): Magnetic particle and Ultrasonic testing
3. Location indicated with (⌒⌒⌒): Ultrasonic testing

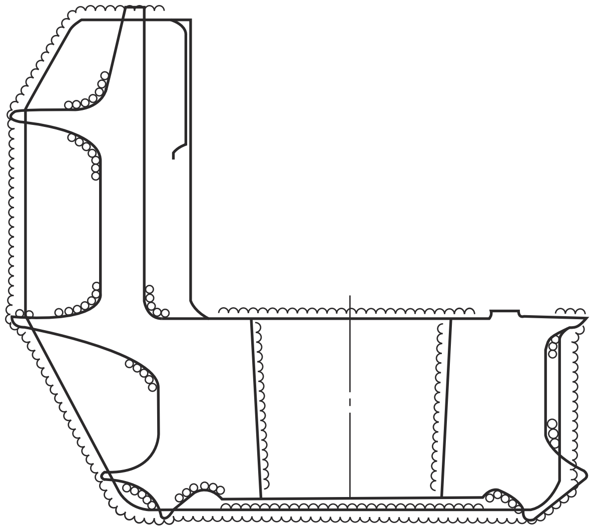
Figure 4.2.4 Extent of non-destructive evaluation for rudder hanging castings



Location of non-destructive examination

1. All surfaces: Visual examination
2. Location indicated with (OOO): Magnetic particle and Ultrasonic testing
3. Location indicated with (⌒⌒⌒): Ultrasonic testing

Figure 4.2.5 Extent of non-destructive evaluation for rudder (upper part) castings



Location of non-destructive examination

1.	All surfaces:	Visual examination
2.	Location indicated with (ooo):	Magnetic particle and Ultrasonic testing
3.	Location indicated with (⌣⌣⌣):	Ultrasonic testing

Figure 4.2.6 Extent of non-destructive evaluation for rudder (lower part) castings

2.5.3 Acceptance levels for Visual Inspection are to be taken as follows:

(a) No cracks or hot tears are permitted.

(b) Castings are to be free of other injurious indications to the satisfaction of the Surveyor.

(c) Additional magnetic particle, dye penetrant or ultrasonic testing may be required for a more detailed evaluation of surface irregularities at the request of the Surveyor. These examinations are in addition to those required by *Ch 4, 2.6 Acceptance levels for surface crack detection*.

2.6 Acceptance levels for surface crack detection

2.6.1 The following definitions apply to indications associated with magnetic particle and dye penetrant inspection:

(a) **Linear indication**. An indication in which the length is at least three times the width.

(b) **Non-linear indication**. An indication of circular or elliptical shape with a length less than three times the width.

(c) **Aligned indication**. Three or more indications in a line, separated by 2 mm or less edge-to-edge.

(d) **Open indication**. An indication visible after removal of the magnetic particles or that can be detected by the use of contrast dye penetrant.

(e) **Non-open indication**. An indication that is not visually detectable after removal of the magnetic particles or that cannot be detected by the use of contrast dye penetrant.

(f) **Relevant indication**. An indication that is caused by a condition or type of discontinuity that requires evaluation. Only indications which have any dimension greater than 1,5 mm are to be considered relevant.

2.6.2 For the purpose of evaluating indications, the surface is to be divided into reference band length of 150 mm for level MT1/PT1 and into reference areas of 225 cm^2 for level MT2/PT2. The band length and/or area is to be taken in the most unfavourable location relative to the indications being evaluated.

2.6.3 The following quality levels recommended for magnetic particle testing (MT) and/or dye penetrant testing (PT) are;

(a) Level MT1/PT1 – fabrication weld preparation areas.

(b) Level MT2/PT2 – other locations indicated on *Figure 4.2.1 Extent of non-destructive evaluation for stern frame castings*.

The acceptance criteria are shown in *Table 4.2.2 Acceptance criteria for surface inspection evaluation*. Cracks and hot tears are not acceptable.

2.6.4 Acceptance criteria for ultrasonic testing are shown in *Table 4.2.3 Ultrasonic acceptance criteria for marine steel castings* as UT1 and UT2. Discontinuities within the examined zones interpreted to be cracks or hot tears are not acceptable.

Table 4.2.2 Acceptance criteria for surface inspection evaluation

Quality level	Maximum number of indication	Type of indication	Maximum number each type	Maximum dimension of single indication, mm (*see* Note 2)
MT1/PT1	4 in 150 mm length	Non-linear Linear Aligned	4, *see* Note 1 4, *see* Note 1 4, *see* Note 1	5 3 3
MT2/PT2	20 in 22500 mm^2 area	Non-Linear Linear Aligned	10 6 6	7 5 5
Note 1. Minimum of 30 mm between relevant indications. Note 2. In weld repairs, the maximum dimension is 2 mm.				

Table 4.2.3 Ultrasonic acceptance criteria for marine steel castings

Quality level	Allowable disc shape according to the Distance-Gain Size (DGS), mm	Maximum number of indications to be registered, *see* Note 1	Allowable length of linear indications, mm, *see* Note 2
UT1	>6	0	0
UT2	12–15 >15	5 0	50 0
Note 1. Grouped in an area measuring 300 x 300 mm. Note 2. Measured on the scanning surface.			

2.6.5 Level UT1 is applicable to the following:

(a) Fabrication weld preparations for a distance of 50 mm.
(b) 50 mm depth from the final machined surface including boltholes.
(c) Fillet radii to a depth of 50 mm and within a distance of 50 mm from the radius end.
(d) Castings subject to cyclic bending stresses, e.g. rudder horn, rudder castings and rudder stocks, the outer one third of thickness in the zones shown in *Figure 4.2.1 Extent of non-destructive evaluation for stern frame castings*.

2.6.6 Level UT2 is applicable to the following:

(a) For locations which are not specified in *Ch 4, 2.6 Acceptance levels for surface crack detection 2.6.5*, nominated for ultrasonic testing in *Figure 4.2.1 Extent of non-destructive evaluation for stern frame castings* or on the inspection plan.
(b) Positions outside locations nominated for level UT1 examination where feeders and gates have been removed.
(c) Castings subject to cyclic bending stresses, at the central one third of thickness in the zones shown in *Figure 4.2.1 Extent of non-destructive evaluation for stern frame castings*.

2.6.7 Ultrasonic acceptance criteria for casting areas not nominated in *Figure 4.2.1 Extent of non-destructive evaluation for stern frame castings* will be subject to special consideration based on the anticipated stress levels and the type, size and position of the discontinuity.

2.6.8 Parts which are welded are to be examined by the same method as at the initial inspection as well as by additional methods as required by the Surveyor.

■ *Section 3*
Castings for machinery construction

3.1 Scope

3.1.1 This Section gives the material requirements for carbon-manganese steel castings intended for use in machinery construction and which are not within the scope of Sections *Ch 4, 4 Castings for crankshafts*.

3.1.2 Where it is proposed to use steels of higher carbon content than is indicated in *Ch 4, 3.2 Chemical composition 3.2.1*, or alloy steels, particulars of the chemical composition, mechanical properties and heat treatment are to be submitted for approval.

3.1.3 The manufacture or repair of cast steel connecting rods is not permitted, except where the manufacturing and quality control procedures have been approved by LR. For approval purposes, tests are to be carried out at the place of manufacture using the proposed process to demonstrate that the castings are sound. Tests are to be carried out to confirm that the appropriate mechanical properties are attained within the casting, including areas where weld repairs have been performed. Any changes to manufacturing, repair and quality control procedures are to be submitted to LR for approval, *see also Ch 1, 2.2 LR Approval – General*.

3.2 Chemical composition

3.2.1 The chemical composition of ladle samples is to comply with the following limits, except as specified in *Ch 4, 3.2 Chemical composition 3.2.2*:

Carbon	0,40% max.
Silicon	0,60% max.
Manganese	0,50-1,60%
Sulphur	0,040% max.
Phosphorus	0,040% max.
Residual elements:	
Copper	0,30% max.
Chromium	0,30% max.
Nickel	0,40% max.
Molybdenum	0,15% max.
	Total 0,80% max.

3.2.2 Castings which are intended for parts of a welded fabrication are to be of weldable quality with a carbon content generally not exceeding 0,23 per cent.

3.2.3 Proposals to use steels with higher carbon content, or alloy steels, for welded construction will be subject to special consideration.

3.3 Heat treatment

3.3.1 Castings are to be supplied:

(a) fully annealed; or
(b) normalised; or
(c) normalised and tempered at a temperature of not less than 550°C; or
(d) quenched and tempered at a temperature of not less than 550°C.

3.3.2 Engine bedplate castings, turbine castings and any other castings where dimensional stability and freedom from internal stresses are important, are to be given a stress relief heat treatment. This is to be at a temperature not lower than 550°C, followed by furnace cooling to 300°C or lower. Alternatively, full annealing may be used provided that the castings are furnace cooled to 300°C or lower.

3.4 Mechanical tests

3.4.1 At least one tensile test is to be made on material representing each casting or batch of castings.

3.4.2 Where the casting is of complex design, or where the finished mass exceeds 10 tonnes, two test samples are to be provided. Where large castings are made from two or more casts which are not mixed in a ladle prior to pouring, two or more test samples are required corresponding to the number of casts involved. The test samples are to be integrally cast at locations as widely separated as possible.

3.4.3 *Table 4.3.1 Mechanical properties for acceptance purposes: carbon and carbon-manganese steel castings for machinery construction* gives the minimum requirements for yield stress, elongation and reduction of area corresponding to different strength levels, but it is not intended that these should necessarily be regarded as specific grades. Intermediate levels of minimum tensile strength may be specified, in which case minimum values for yield stress, elongation and reduction of area may be obtained by interpolation.

Table 4.3.1 Mechanical properties for acceptance purposes: carbon and carbon-manganese steel castings for machinery construction

Tensile strength N/mm^2	Yield stress N/mm^2 minimum	Elongation on 5,65 $\sqrt{S_0}$ % minimum	Reduction of area % minimum
400 – 550	200	25	40
440 – 590	220	22	30
480 – 630	240	20	27
520 – 670	260	18	25
560 – 710	300	15	20
600 – 750	320	13	20

3.4.4 Castings may be supplied to any specified minimum tensile strength selected within the general limits detailed in *Table 4.3.1 Mechanical properties for acceptance purposes: carbon and carbon-manganese steel castings for machinery construction*.

3.4.5 The results of all tensile tests are to comply with the requirements of *Table 4.3.1 Mechanical properties for acceptance purposes: carbon and carbon-manganese steel castings for machinery construction* appropriate to the specified minimum tensile strength.

3.4.6 For alloy steel castings and carbon-manganese steel castings containing more than 0,40 per cent carbon, the results of all mechanical tests are to comply with an approved specification.

3.4.7 When a casting, or a batch of castings, has failed to meet the mechanical test requirements, it may be re-heat treated and re-submitted for acceptance tests but this may not be carried out more than twice, *see Ch 1, 4.6 Re-test procedures*.

3.5 Non-destructive examination

3.5.1 All piston crowns and cylinder heads are to be examined by ultrasonic testing unless otherwise agreed with LR. Piston crowns intended for engines having a bore size larger than 400 mm and cylinder heads intended for engines having a bore size larger than 300 mm are additionally to be examined by magnetic particle or penetrant testing in accordance with *Ch 4, 1.7 Visual and non-destructive examination*.

3.5.2 Engine bedplate and transverse girder castings are to be examined by ultrasonic and magnetic particle or penetrant testing in accordance with *Ch 4, 1.7 Visual and non-destructive examination*.

3.5.3 Turbine castings are to be examined by magnetic particle or dye penetrant testing in accordance with *Ch 4, 1.7 Visual and non-destructive examination*. In addition, an ultrasonic or radiographic examination is to be made in way of fabrication weld preparations.

3.5.4 Other castings are to be examined by non-destructive methods where specified.

Section 4
Castings for crankshafts

4.1 Scope

4.1.1 This Section gives the requirements for carbon and carbon-manganese steel castings for semi-built crankshafts.

4.1.2 Where it is proposed to use steels of higher carbon content than is indicated in *Ch 4, 4.3 Chemical composition 4.3.1*, or alloy steels, particulars of the chemical composition, mechanical properties and heat treatment are to be submitted for approval. For alloy steels, the specified minimum tensile strength is not to exceed 700 N/mm^2.

4.2 Manufacture

4.2.1 The method of producing combined web and pin castings is to be approved. For this purpose, tests to demonstrate the soundness of the casting and the properties at important locations may be required.

4.3 Chemical composition

4.3.1 The chemical composition of ladle samples is to comply with the following limits:

Carbon	0,40% max. (*but see Ch 4, 4.7 Rectification of defective castings 4.7.4*)
Silicon	0,60% max.
Manganese	0,50-1,60%
Sulphur	0,040% max.
Phosphorus	0,040% max.
Residual elements:	
Copper	0,30% max.
Chromium	0,30% max.
Nickel	0,40% max.
Molybdenum	0,15% max.
	Total 0,80% max.

4.4 Heat treatment

4.4.1 Castings are to be supplied either:

(a) fully annealed and cooled in the furnace to a temperature of 300°C or lower; or
(b) normalised and tempered at a temperature of not less than 550°C, and cooled in the furnace to a temperature of 300°C or lower.

4.5 Mechanical tests

4.5.1 Proposals for the number of tests and the location of test material on the casting are to be submitted by the manufacturer.

4.5.2 Not less than one tensile test and three impact tests are to be made on material representing each casting. The impact tests are to be carried out at ambient temperature.

4.5.3 *Table 4.4.1 Mechanical properties for acceptance purposes: carbon - manganese steel castings for crankshafts* gives the minimum requirements for yield stress and elongation corresponding to different strength levels, and it is not intended that these should necessarily be regarded as specific grades. The strength levels have been given in multiples of 40 N/mm^2 to facilitate interpolation for intermediate values of specified minimum tensile strength.

4.5.4 Castings may be supplied to any specified minimum tensile strength selected within the general limits detailed in *Table 4.4.1 Mechanical properties for acceptance purposes: carbon - manganese steel castings for crankshafts*.

4.5.5 The results of all tests are to comply with the requirements of *Table 4.4.1 Mechanical properties for acceptance purposes: carbon - manganese steel castings for crankshafts* appropriate to the specified minimum tensile strength. For the impact tests, one individual value may be less than the required average value provided that it is not less than 70 per cent of this average value. *See Ch 1, 4.6 Re-test procedures* for re-test procedures.

4.6 Non-destructive examination

4.6.1 Magnetic particle examination is to be carried out over all surfaces in accordance with *Figure 4.4.1 Magnetic particle inspection acceptance levels*.

Table 4.4.1 Mechanical properties for acceptance purposes: carbon - manganese steel castings for crankshafts

Tensile strength N/mm^2	Yield stress N/mm^2 minimum	Elongation on $5,65\sqrt{S_0}$ % minimum	Reduction of area % minimum	Charpy V-notch impact tests average energy J minimum (*see* Note)
400 – 550	200	28	45	32
440 – 590	220	26	45	28
480 – 630	240	24	40	25
520 – 670	260	22	40	20
550 – 700	275	20	35	18
Note Impact tests are to be made at ambient temperature.				

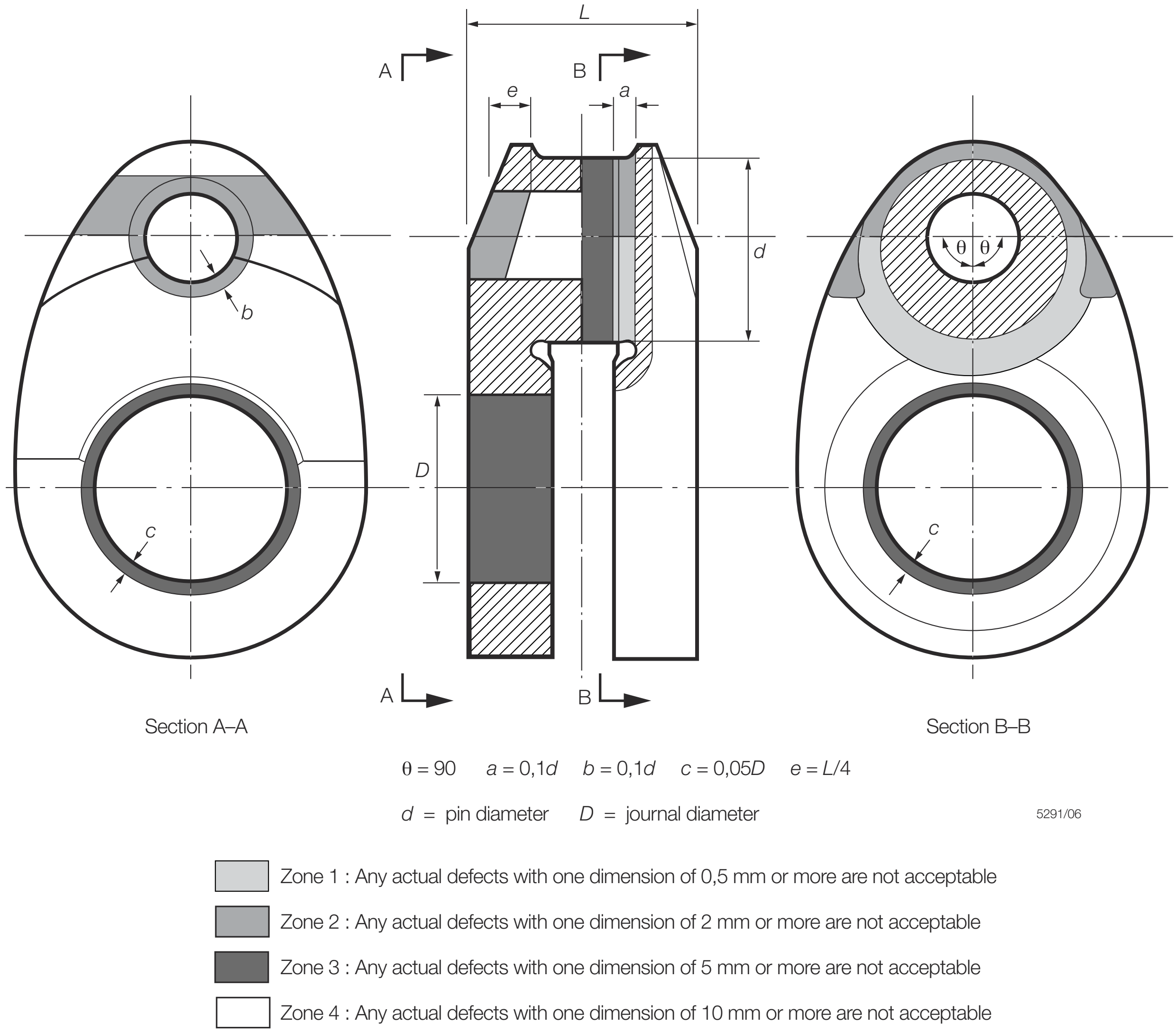


Figure 4.4.1 Magnetic particle inspection acceptance levels

4.6.2 Each casting is to be examined by ultrasonic testing, and the extent of examination and defect acceptance criteria, using the DGS (Distance Gain Size) technique, are to be as shown in *Figure 4.4.2 Ultrasonic examination acceptance levels*. Alternative ultrasonic procedures may be submitted for approval.

4.7 Rectification of defective castings

4.7.1 The requirements of *Ch 4, 1.9 Rectification and dressing of castings* apply, except where amended by this Section.

4.7.2 Where castings have shallow surface defects, consideration is first to be given to removing such defects by grinding and blending or by machining the surface where there is excess metal on the Rule dimension.

4.7.3 Subject to prior agreement and submission of the detailed welding procedure for approval by LR, welding may be carried out prior to the final austenitising heat treatment.

4.7.4 Approval for welding will not be given in the following circumstances:

(a) For the rectification of repetitive defects caused by improper foundry technique or practice.
(b) For the building up by welding of surfaces or large shallow depressions.
(c) Where the carbon content of the steel exceeds 0,30 per cent.

(d) Where the carbon equivalent of the steel, given by

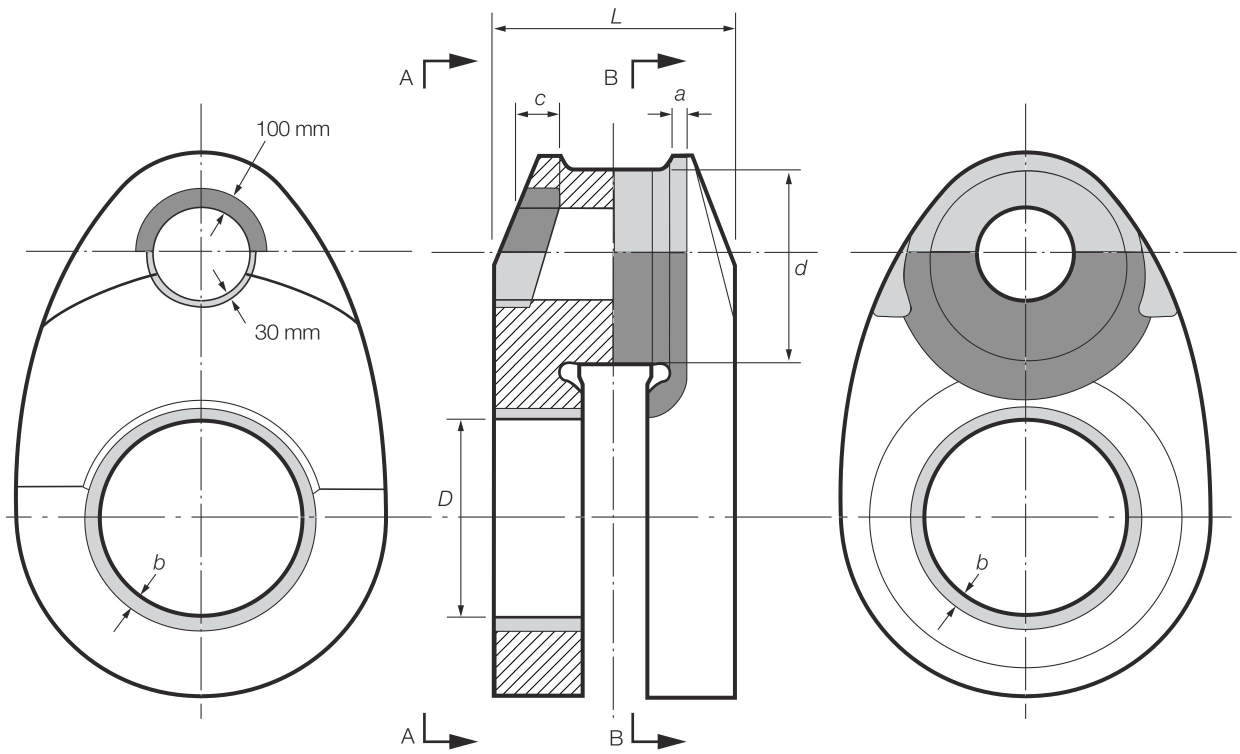
$$\mathrm{C} + \frac{\mathrm{Mn}}{6} + \frac{\mathrm{Cr} + \mathrm{Mo} + \mathrm{V}}{5} + \frac{\mathrm{Ni} + \mathrm{Cu}}{15} \ exceeds 0,65 percent.$$

4.7.5 Provided that the Surveyors are satisfied that welding is justified, they may also authorise welding to the surfaces of crankwebs, following the final austenitising heat treatment, within the following limits:

(a) In general, the volume of the largest groove which is to be welded is not to exceed 3,2*t* cm^3, where *t* is the web axial thickness, in cm. The total volume of all grooves which are to be welded is not to exceed 9,6*t* cm^3 per crankweb.
(b) The welds do not extend within the cross-hatched zones marked on *Figure 4.4.3 Areas of semi-built crankthrows to which weld repairs are not permitted* for semi-built crankthrows.
(c) Larger welds on balance weights may be permitted at the discretion of the Surveyor, provided that such repairs are wholly contained within the balance weight and do not affect the strength of the crankweb.

4.7.6 Subsequent to the final austenitising heat treatment, welding may be authorised in the surface of the bore for the journal (or pin) within the following limits:

(a) In general, the welds are to be not less than 125 mm apart.
(b) The welds are not to be located within circumferential bands of $\frac{t}{5}$ from the edges of the bores, nor at any position within the inner 120° arc of the bores, as cross-hatched on *Figure 4.4.3 Areas of semi-built crankthrows to which weld repairs are not permitted*.
(c) The volume of the largest weld is to be not more than 1,1*t* cm^3, where *t* is the web axial thickness at the bore, in cm, and not more than three welds are to be made in any one bore surface.



a = 0,1d b = 0,05D c = L/6

d = Pin diameter D = Journal diameter

5291/07

Zone 1 : Max. allowable flaw size equivalent to a flat bottomed diameter 3 mm hole

Zone 2 : Max. allowable flaw size equivalent to a flat bottomed diameter 6 mm hole

Figure 4.4.2 Ultrasonic examination acceptance levels

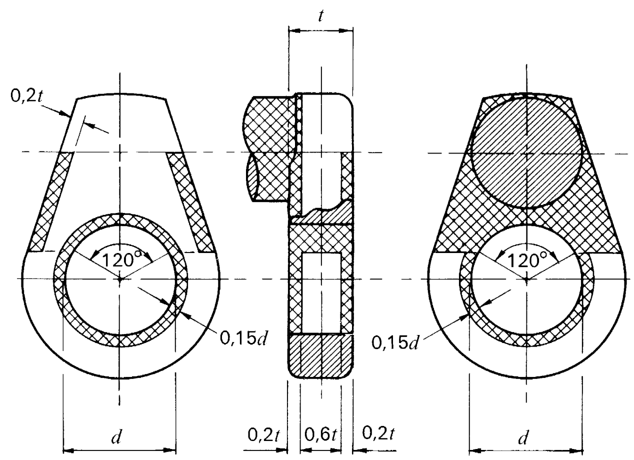


Figure 4.4.3 Areas of semi-built crankthrows to which weld repairs are not permitted

4.7.7 After all defective material has been removed from a region, and this has been proven in the presence of the Surveyor by magnetic particle inspection or other suitable method, the excavation is to be suitably shaped to allow good access for welding.

4.7.8 At the discretion of the Surveyor, the size of a groove may be increased beyond the limiting sizes given in *Ch 4, 4.7 Rectification of defective castings 4.7.5* or *Ch 4, 4.7 Rectification of defective castings 4.7.6*, if the removal of further metal will facilitate welding.

4.7.9 Welding is to be carried out by approved welders using approved procedures. The welds are to be made by an electric arc process using low hydrogen type consumables which will produce a deposited metal that is not inferior in properties to the parent metal.

4.7.10 All castings are to be given a preliminary refining heat treatment prior to the commencement of welding. Before welding, the material is to be preheated in accordance with the qualified procedure. Where possible, preheating is to be carried out in a furnace. The preheat temperature is to be maintained until welding is completed, and preferably until the casting is placed in the furnace for post-weld heat treatment.

4.7.11 Where welding is carried out after the final austenitising heat treatments, a post-weld stress relieving heat treatment is to be applied at a temperature of not less than 600°C, *see also Ch 4, 1.5 Heat treatment 1.5.2*.

4.7.12 Welds are to be dressed smooth by grinding. The surfaces of the welds and adjacent parent steel are to be proven by magnetic particle and, where appropriate, ultrasonic inspection, *see Ch 4, 1.9 Rectification and dressing of castings 1.9.15* and *Ch 4, 1.9 Rectification and dressing of castings 1.9.15*.

■ *Section 5*
Castings for propellers

5.1 Scope

5.1.1 This Section gives the requirements for steel castings for one-piece propellers and separately cast blades and hubs for fixed pitch and controllable pitch propellers (CPP). These include contra-rotating propellers, azipods and azimuth thrusters. The requirements for copper alloy propellers, blades and hubs are given in *Ch 9, 1 Castings for propellers*.

5.1.2 These castings are to be manufactured and tested in accordance with the appropriate requirements of *Ch 1 General Requirements* and *Ch 2 Testing Procedures for Metallic Materials* and *Ch 4, 1 General requirements* as well as the requirements of this Section.

5.1.3 Full details of the manufacturer's specification are to be submitted for approval. These should include the chemical composition, heat treatment, mechanical properties, microstructure and repair procedures.

5.1.4 Special requirements are given for castings which are intended for ice service in *Table 4.5.2 Typical mechanical properties for steel propeller castings*.

5.2 Chemical composition

5.2.1 The chemical composition of ladle samples is to comply with the approved specification, *see Ch 4, 5.1 Scope 5.1.3*.

5.2.2 Typical cast steel propeller alloys are given in *Table 4.5.1 Typical chemical composition for steel propeller castings*.

Table 4.5.1 Typical chemical composition for steel propeller castings

Alloy type	C Max. (%)	Mn Max. (%)	Cr (%)	Mo Max. (%) (*see* Note)	Ni (%)
Martensitic (12Cr 1Ni)	0,15	2,0	11,5 – 17,0	0,5	Max. 2,0
Martensitic (13Cr 4Ni)	0,06	2,0	11,5 – 17,0	1,0	3,5 – 5,0
Martensitic (16Cr 5Ni)	0,06	2,0	15,0 – 17,5	1,5	3,5 – 6,0

Austenitic (19Cr 11Ni)	0,12	1,6	16,0 – 21,0	4,0	8,0 – 13,0
Note Minimum values are to be in accordance with the agreed specification or recognised National or International Standards.					

5.3 Heat treatment

5.3.1 Martensitic stainless steel castings are to be austenitised, quenched and tempered in accordance with the approved specification, *see Ch 4, 5.1 Scope 5.1.3*.

5.3.2 Austenitic stainless steel castings are to be solution treated in accordance with the approved specification, *see Ch 4, 5.1 Scope 5.1.3*.

5.4 Mechanical tests

5.4.1 The test material is to be cast integral with the boss of propeller castings, or with the flange of separately cast propeller blades. Alternatively, the test material may be attached on blades in an area between 0,5 and 0,6*R*, where *R* is the radius of the propeller.

5.4.2 The test material is not to be removed from the casting until final heat treatment has been carried out. Removal is to be by non-thermal procedures.

5.4.3 At least one tensile test and for the martensitic stainless steel grades one set of three Charpy V-notch impact tests are to be made on material representing each casting. The results are to comply with the requirements of *Table 4.5.2 Typical mechanical properties for steel propeller castings* or the approved specification.

Table 4.5.2 Typical mechanical properties for steel propeller castings

Alloy type	Yield stress or, 0,2% proof stress minimum, N/mm^2	Tensile strength minimum N/mm^2	Elongation on 5,65 $\sqrt{So}$ % minimum	Reduction of area % minimum	Charpy V-notch impact tests J minimum (*see* Notes 1 and 2)
Martensitic (12Cr 1Ni)	440	590	15	30	20
Martensitic (13Cr 4Ni)	550	750	15	35	30
Martensitic (16Cr 5Ni)	540	760	15	35	30
Austenitic (19Cr 11Ni)	180 (*see* Note 3)	440	30	40	-
Note 1. When a general service notation **Ice Class 1AS, 1A, 1B or 1C** is required, the tests are to be made at –10°C.					
Note 2. For general service or where the notation **Ice Class 1D** is required, the tests are to be made at 0°C.					
Note 3. $R_{p1,0}$ value is 205 N/mm^2.					

5.4.4 As an alternative to *Ch 4, 5.4 Mechanical tests 5.4.3*, where a number of small propeller castings of about the same size, and less than 1 m in diameter, are made from one cast and heat treated together in the same furnace, a batch testing procedure may be adopted using separately cast test samples of suitable dimensions. At least one set of mechanical tests is to be provided for each multiple of five castings in the batch.

5.4.5 Separately cast test bars may be used subject to prior approval of the Surveyor. Test bars must be cast from the same heat, or heats, and must also be heat treated with castings they represent.

5.5 Non-destructive examination

5.5.1 On completion of machining and grinding, the whole surface of each casting is to be examined in accordance with *Ch 9, 1.8 Inspection and non-destructive examination*.

5.5.2 When appropriate, magnetic particle inspection may be used in lieu of liquid penetrant testing.

5.5.3 Castings are to be free from cracks and hot tears.

5.6 Rectification of defective castings

5.6.1 The rectification of defective castings is to be undertaken in accordance with *Ch 4, 1.9 Rectification and dressing of castings* and the following paragraphs.

5.6.2 Removal of defective material is to be by mechanical means, e.g. by grinding, chipping or milling. The resultant grooves are to be blended into the surrounding surface so as to avoid any sharp contours.

5.6.3 Grinding in severity zone A may be carried out to an extent that maintains the blade thickness. Repair by welding is generally not permitted in zone A and will only be allowed after special consideration.

5.6.4 Defects in severity zone B that are not deeper than t/40 mm (t is the minimum local thickness according to the Rules) or 2 mm, whichever is the greater, are to be removed by grinding. Those defects that are deeper may be repaired by welding subject to prior approval of the Surveyor.

5.6.5 Repair welding is generally permitted in severity zone C.

5.6.6 Welds having an area of less than 5 cm^2 are to be avoided. The maximum surface area of repairs is to be in accordance with *Table 9.1.4 Permissible rectification of new propellers by welding* in Chapter 9.

5.6.7 Welding is to be in accordance with the approved specification, *see Ch 4, 5.1 Scope 5.1.3*.

5.6.8 After weld repair, the propeller or blade is to be heat treated in such fashion as will minimise the residual stresses. For martensitic stainless steels, this will involve full heat treatment as specified in the approved specification.

5.6.9 LR reserves the right to restrict the amount of repair work accepted from a manufacturer when it appears that repetitive defects are the result of improper foundry techniques or practices.

5.6.10 All welds are to be inspected by the appropriate NDE method, *see Ch 4, 1.7 Visual and non-destructive examination*.

5.7 Identification

5.7.1 Castings are to be clearly marked by the manufacturer in accordance with the requirements of *Ch 1 General Requirements*. The following details are to be shown on all castings which have been accepted:

(a) Identification mark which will enable the full history of the item to be traced.
(b) Type of steel, this should include or allow identification of the chromium and nickel contents.
(c) LR or Lloyd's Register and the abbreviated name of Lloyd's Register's local office.
(d) Personal stamp of Surveyor responsible for the final inspection.
(e) LR certificate number.
(f) Skew angle, if in excess of 25°.
(g) Ice class symbol, where applicable.
(h) Date of final inspection.

5.8 Certification of materials

5.8.1 In addition to the requirements in *Ch 4, 1.11 Certification of materials*, the manufacturer is to provide the Surveyor with a written statement giving the following particulars for each casting:

(a) Description of casting with drawing number.
(b) Diameter, number of blades, pitch, direction of turning.
(c) Skew angle, if in excess of 25°
(d) Final mass.
(e) Vessel identification, where known.

■ *Section 6*
Castings for boilers, pressure vessels and piping systems

6.1 Scope

6.1.1 This Section gives the requirements for carbon-manganese and alloy steel castings for boilers, pressure vessels and piping systems for use at temperatures not lower than 0°C.

6.1.2 Where it is proposed to use alloy steels other than as given in this Section, details of the specification are to be submitted for approval. In such cases, the specified minimum tensile strength is not to exceed 600 N/mm^2.

6.1.3 Castings which comply with these requirements are acceptable for liquefied gas piping systems where the design temperature is not lower than 0°C. Where the design temperature is lower than 0°C, and for other applications where guaranteed impact properties at low temperatures are required, the castings are to comply with the requirements of *Ch 4, 7 Ferritic steel castings for low temperature service* or *Ch 4, 8 Stainless steel castings*.

6.2 Chemical composition

6.2.1 The chemical composition of ladle samples is to comply with the limits specified in *Table 4.6.1 Chemical composition of steel castings for boilers, pressure vessels and piping systems*.

6.3 Heat treatment

6.3.1 Castings are to be supplied:

(a) fully annealed; or
(b) normalised; or
(c) normalised and tempered; or
(d) quenched and tempered.

6.4 Mechanical tests

6.4.1 A tensile test is to be made on material representing each casting, unless a batch testing procedure has been agreed, *see Ch 4, 1.6 Test material and test specimens*.

6.4.2 The tensile test is to be carried out at ambient temperature, and unless agreed otherwise with the Surveyor the results are to comply with the requirements of *Table 4.6.2 Mechanical properties for acceptance purposes: steel castings for boilers, pressure vessels and piping systems*.

Table 4.6.1 Chemical composition of steel castings for boilers, pressure vessels and piping systems

Type of steel	Chemical composition %										
	C max.	Si max.	Mn	S max.	P max.	Residual elements					
Carbon-manganese	0,25	0,60	0,50-1,20	0,040	0,040	Cr 0,30 max. Mo 0,15 max. Cu 0,30 max. Ni 0,40 max. Total 0,80 max.					
						Cr	Mo	V	Residual elements		
									Cr	Cu	Ni
$^1/_2$ Mo	0,20	0,60	0,50–1,00	0,040	0,040	–	0,45-0,65	–	0,30 max.	0,30 max.	0,40 max.
1 Cr $^1/_2$ Mo	0,20	0,60	0,50-0,80	0,040	0,040	1,00-1,50	0,45-0,65	–	–	0,30 max.	0,40 max.
2 $^1/_4$ Cr1 Mo	0,18	0,60	0,40-0,70	0,040	0,040	2,00-2,75	0,90-1,20	–	–	0,30 max.	0,40 max.
$^1/_2$ Cr $^1/_2$ Mo $^1/_4$ V	0,10–0,15	0,45	0,40-0,70	0,030	0,030	0,30-0,50	0,40-0,60	0,22-0,30	–	0,30 max.	0,30 max.

Table 4.6.2 Mechanical properties for acceptance purposes: steel castings for boilers, pressure vessels and piping systems

Type of steel	Yield stress minimum N/mm^2	Tensile strength N/mm^2	Elongation on 5,65 $\sqrt{S_0}$ % minimum	Reduction of area % minimum
Carbon-manganese	275	485-655	22	25
$^1/_2$ Mo	260	460-590	18	30
1 Cr $^1/_2$ Mo	280	480-630	17	20
2 $^1/_4$ Cr1 Mo	325	540-630	17	20
$^1/_2$ Cr $^1/_2$ Mo $^1/_4$ V	295	510-660	17	20

Table 4.6.3 Mechanical properties for design purposes (*see* 6.6.1)

Type of steel	Nominal minimum lower yield or 0,2% proof stress N/mm^2										
	Temperature °C										
	100	150	200	250	300	350	400	450	500	550	600
Carbon-manganese	225	214	201	186	163	156	152	–	–	–	–
$^1/_2$ Mo	242	236	226	207	186	175	169	158	145	136	126
1 Cr $^1/_2$ Mo	240	–	212	–	196	–	184	–	160	–	117
2 $^1/_4$ Cr1 Mo	323	312	305	296	290	280	273	258	240	211	180
$^1/_2$ Cr $^1/_2$ Mo $^1/_4$ V	264	–	244	–	230	–	214	–	194	–	144

6.4.3 Where it is proposed to use a carbon-manganese steel with a specified minimum tensile strength intermediate to those given in this Section, corresponding minimum values for the yield stress, elongation and reduction of area may be obtained by interpolation.

6.4.4 Carbon-manganese steels with a specified minimum tensile strength of greater than 490 N/mm^2, but not exceeding 520 N/mm^2, may be accepted provided that details of the proposed specification are submitted for approval.

6.5 Non-destructive examination

6.5.1 The non-destructive examination of castings is to be carried out in accordance with the appropriate requirements of *Ch 4, 1.7 Visual and non-destructive examination 1.7.7* and additionally as agreed between the manufacturer, purchaser and Surveyor.

6.6 Mechanical properties for design purposes

6.6.1 Nominal values for the minimum lower yield or 0,2 per cent proof stress at temperatures of 100°C and higher are given in *Table 4.6.3 Mechanical properties for design purposes (see 6.6.1)* . These values are intended for design purposes only, and verification is not required except for materials complying with National or proprietary specifications where the elevated temperature properties used for design purposes are higher than those given in *Table 4.6.3 Mechanical properties for design purposes (see 6.6.1)* .

6.6.2 In such cases, at least one tensile test at the proposed design or other agreed temperature is to be made on each casting or each batch of castings. The test specimen is to be taken from material adjacent to that used for tests at ambient temperature, and the test procedure is to be in accordance with the requirements of *Ch 2 Testing Procedures for Metallic Materials*. The results of all tests are to comply with the requirements of the National or proprietary specification.

6.6.3 Values for the estimated average stress to rupture in 100 000 hours are given in *Table 4.6.4 Mechanical properties for design purposes (see 6.6.3): estimated average stresses to rupture in 100,000 hours (N/mm^2)* and may be used for design purposes.

Table 4.6.4 Mechanical properties for design purposes (*see* 6.6.3): estimated average stresses to rupture in 100,000 hours (N/mm^2)

Temperature °C	Type of steel			
	½Mo	1Cr½Mo	2¼Cr1Mo	½Cr½Mo¼V
430	308	–	–	–
440	276	–	–	–
450	245	–	222	277
460	212	–	199	237
470	174	236	177	206
480	133	186	156	181
490	103	148	139	159
500	84	120	124	140
510	71	100	111	124
520	60	84	99	109
530	–	70	–	96
540	–	58	–	85
550	–	–	–	75
560	–	–	–	66

■ *Section 7*
Ferritic steel castings for low temperature service

7.1 Scope

7.1.1 This Section gives the requirements for castings in carbon-manganese and nickel alloy steels intended for use in liquefied gas piping systems where the design temperature is lower than 0°C, and for other applications where guaranteed impact properties at low temperatures are required.

7.1.2 Where it is proposed to use alternative steels, particulars of the specified chemical composition, mechanical properties and heat treatment are to be submitted for approval.

7.2 Chemical composition

7.2.1 The chemical composition of ladle samples is to comply with the limits specified in *Table 4.7.1 Chemical composition of ferritic steel castings for low temperature service*. Carbon-manganese steels are to be made by fine grain practice.

7.3 Heat treatment

7.3.1 Castings are to be supplied:

(a) normalised; or
(b) normalised and tempered; or
(c) quenched and tempered.

7.4 Mechanical tests

7.4.1 One tensile test and one set of three Charpy V-notch impact test specimens are to be prepared from material representing each casting or batch of castings.

7.4.2 The tensile test is to be carried out at ambient temperature, and the results are to comply with the appropriate requirements given in *Table 4.7.2 Mechanical properties for acceptance purposes: ferritic steel castings for low temperature service*.

7.4.3 The average value for impact test specimens is to comply with the appropriate requirements given in *Table 4.7.2 Mechanical properties for acceptance purposes: ferritic steel castings for low temperature service*. One individual value may be less than the required average value provided that it is not less than 70 per cent of this average value. *See Ch 2, 1.4 Re-testing procedures* for re-test procedure.

7.5 Non-destructive examination

7.5.1 The non-destructive examination of castings is to be carried out in accordance with the appropriate requirements of *Ch 4, 1.7 Visual and non-destructive examination 1.7.7*, and additionally agreed between the manufacturer, purchaser and Surveyor.

Table 4.7.1 Chemical composition of ferritic steel castings for low temperature service

Type of steel	Chemical composition %						
	C max.	Si max.	Mn	S max.	P max.	Ni	Residual elements max.
Carbon-manganese	0,23	0,60	0,70-1,60	0,030	0,030	0,80 max.	Cr 0,25 Cu 0,30 Mo 0,15 V 0,03 Total 0,60
2 $^{1}/_{4}$Ni	0,25	0,60	0,50-0,80	0,025	0,030	2,00-3,00	
3 $^{1}/_{2}$Ni	0,15	0,60	0,50-0,80	0,020	0,025	3,00-4,00	

Table 4.7.2 Mechanical properties for acceptance purposes: ferritic steel castings for low temperature service

Type of steel	Grade	Yield stress N/mm^2 minimum	Tensile strength N/mm^2	Elongation on 5,65 $\sqrt{S_0}$ % minimum	Reduction of area % minimum	Charpy V-notch impact test	
						Test temperature °C	Average energy J minimum
Carbon-manganese	400	200	400-550	25	40		
	430	215	430-580	23	35	–60(*see* Note)	27
	460	230	460-610	22	30		
2$^{1}/_{4}$Ni	490	275	490-640	20	35	–70	34
3 $^{1}/_{2}$Ni	490	275	490-640	20	35	–95	34

Note The test temperature for carbon-manganese steels may be 5°C below the design temperature if the latter is above –55°C, with a maximum test temperature of –20°C.

■ *Section 8*
Stainless steel castings

8.1 Scope

8.1.1 This Section gives the requirements for castings in austenitic and duplex stainless steels for machinery, marine structures, piping systems in ships for liquefied gases, and in bulk chemical tankers.

8.1.2 Austenitic stainless steels castings are suitable for applications where the lowest design temperature is not lower than –165°C.

8.1.3 Duplex stainless steels castings are suitable for applications where the lowest design temperature is above 0°C. Any requirement to use duplex stainless steels castings below 0°C will be subject to special consideration.

8.1.4 Where it is proposed to use alternative steels, particulars of the specified chemical composition, mechanical properties and heat treatment are to be submitted for approval.

8.2 Chemical composition

8.2.1 The chemical composition of ladle samples is to comply with the requirements given in *Table 4.8.1 Chemical composition of stainless steel castings*.

8.3 Heat treatment

8.3.1 Austenitic stainless steel castings are to be solution treated at a temperature of not less than 1000°C and cooled rapidly in water.

8.3.2 Duplex stainless steels castings are to be solution treated at a temperature of not less that 1100°C and cooled rapidly in water.

8.4 Mechanical tests

8.4.1 One tensile test specimen is to be prepared from material representing each casting or batch of castings. In addition, where the castings are intended for liquefied gas applications, where the design temperature is lower than –55°C, one set of three Charpy V-notch impact test specimens is to be prepared.

Table 4.8.1 Chemical composition of stainless steel castings

<table>
<tr><td rowspan="2">Type of steel</td><td colspan="9">Chemical composition %</td></tr>
<tr><td>C</td><td>Si</td><td>Mn</td><td>S</td><td>P</td><td>Cr</td><td>Mo</td><td>Ni</td><td>Others</td></tr>
<tr><td colspan="10">Austenitic</td></tr>
<tr><td>304L</td><td>0,03</td><td rowspan="8">0,20-1,5</td><td rowspan="8">0,50-2,0</td><td colspan="2" rowspan="8">0,040</td><td rowspan="8">17,0-21,0</td><td>—</td><td>8,0–12,0</td><td>—</td></tr>
<tr><td>304</td><td>0,08</td><td>—</td><td>8,0–12,0</td><td>—</td></tr>
<tr><td>316L</td><td>0,03</td><td>2,0–3,0</td><td>9,0–13,0</td><td>—</td></tr>
<tr><td>316</td><td>0,08</td><td>2,0–3,0</td><td>9,0–13,0</td><td>—</td></tr>
<tr><td>317</td><td>0,08</td><td>3,0–4,0</td><td>9,0–12,0</td><td>—</td></tr>
<tr><td></td><td></td><td rowspan="3">—</td><td rowspan="3">9,0–12,0</td><td rowspan="3">Nb
≥ 8 x C
≤0,90</td></tr>
<tr><td>347</td><td>0,06</td></tr>
<tr><td>(*see* Note 1)</td><td></td></tr>
<tr><td colspan="10">Duplex</td></tr>
</table>

UNS J 92205 (*see* Note 3)	0,03	1,00	1,50	0,020	0,035	21,0–23,0	2,5–3,5	4,5–6,5	N 0,15–0,20 Cu 1,00
Note 1. When guaranteed impact values at low temperature are not required, the maximum carbon content may be 0,08% and the maximum niobium may be 1,00%. Note 2. Where a single value is shown (and not a range of values), the value is to be taken as maximum. Note 3 The grade UNS J 92205 is the cast equivalent of UNS S 31803.									

Table 4.8.2 Mechanical properties for acceptance purposes: austenitic stainless steel castings

Type of steel	Tensile strength N/mm^2 minimum	1,0% proof stress N/mm^2 minimum	Elongation on 5,65 $\sqrt{S_0}$ % minimum	Reduction of area % minimum	Charpy V-notch impact test	
					Test temperature °C	Average energy J minimum
Austenitic						
304L	430	215	26	40	–196	41
304	480	220				
316L	430	215	26	40	–196	41
316	480	220				
317	480	240				
347	480	215	22	35	–196	41
Duplex						
UNS J 92205 (*see* Note)	600	420	20	35	0	41
Note The grade UNS J 92205 is the cast equivalent of UNS S 31803.						

8.4.2 The tensile test is to be carried out at ambient temperature, and the results are to comply with the requirements given in *Table 4.8.2 Mechanical properties for acceptance purposes: austenitic stainless steel castings*.

8.4.3 The average value for impact test specimens is to comply with the appropriate requirements given in *Table 4.8.2 Mechanical properties for acceptance purposes: austenitic stainless steel castings*. One individual value may be less than the required average value provided that it is not less than 70 per cent of this average value. *See Ch 2, 1.4 Re-testing procedures* for re-test procedures.

8.5 Corrosion tests

8.5.1 Where corrosive conditions are anticipated in service, for grades 304, 316 and 317, intergranular corrosion tests are required in accordance with *Ch 2, 9.1 Intergranular corrosion test*. Such tests may also be required for grades 304L, 316L and 347.

8.5.2 Where corrosive conditions are anticipated in service, for duplex stainless pitting corrosion tests are required in accordance with *Ch 2, 9.2 Pitting corrosion test* . For UNS J 92205 the test temperature is to be 20°C.

8.6 Non-destructive examination

8.6.1 The non-destructive examination of castings is to be carried out in accordance with the appropriate requirements of *Ch 4, 1.7 Visual and non-destructive examination 1.7.7* and additionally agreed between the manufacturer, purchaser and Surveyor.

Section 9
Steel castings for container corner fittings

9.1 General

9.1.1 This Section gives the requirements for cast steel corner fittings used in the fabrication of freight and tank containers. The fittings are also to comply with the requirements of the latest edition of International Standard ISO 1161.

9.1.2 The castings are to be made in foundries approved by LR. These foundries are also to be specially approved for the manufacture of container corner castings. In order to comply with these requirements, the manufacturer is required to verify that the casting soundness, mechanical properties, weldability and dimensional tolerances required by this Section and the manufacturing specification are met.

9.1.3 Castings may be released on the basis of an LR survey or, alternatively, the manufacturer may be approved by means of a Quality Assurance Scheme as detailed in *Ch 1, 2 Approval and survey requirements*.

9.2 Chemical composition

9.2.1 Chemical analysis is to be carried out on each cast.

9.2.2 The chemical composition of the ladle samples is to comply with the limits given in *Table 4.9.1 Chemical composition of steel castings for container corner fittings*.

9.2.3 The carbon equivalent

$$\mathrm{C_{eq}} = \mathrm{C} + \frac{\mathrm{Mn}}{6} + \frac{\mathrm{Cr} + \mathrm{Mo} + \mathrm{V}}{5} + \frac{\mathrm{Ni} + \mathrm{Cu}}{15}\ (\%)$$

must not exceed 0,45 per cent.

9.3 Heat treatment

9.3.1 Castings are to be supplied either :

(a) normalised; or
(b) water or oil quenched and tempered at a temperature of not less than 550°C.

9.4 Mechanical tests

9.4.1 At least one tensile test is to be made on each batch of castings, using separately cast test bars which are to be from the same cast and heat treatment lot as the castings they represent.

Table 4.9.1 Chemical composition of steel castings for container corner fittings

Chemical composition %										
C max.	Mn	Si max.	P max.	S max.	Cr max.	Ni max.	Cu max.	Mo max.	Al acid soluble min. (*See* Notes)	Cr + Ni + Cu + Mo max.
0,20	0,90 to 1,50	0,50	0,035	0,035	0,25	0,30	0,20	0,08	0,015	0,70
Note 1. The total aluminium content may be determined instead of the acid soluble content. In such cases, the total aluminium content is to be not less than 0,02%.										
Note 2. Aluminium may be replaced partly or totally by other grain refining elements as stated in the approved specification.										

9.4.2 The results of the tensile tests are to comply with the following:

Yield stress	220 N/mm^2 min.
Tensile strength	430 - 600 N/mm^2
Elongation on $\sqrt{S_o}$	25% min.
Reduction of area	40% min.

9.4.3 Impact tests are not required on all casts but may be required on a random basis at the discretion of the Surveyor.

9.4.4 When required, the impact test specimens are to be tested in accordance with *Ch 1, 4.5 Mechanical tests* and *Ch 2, 3.2 Testing procedures*. In general, tests are to be made at a temperature of -20°C and the minimum average energy obtained is to be 27J.

9.5 Non-destructive examination

9.5.1 Ultrasonic or radiographic testing is to be carried out, in accordance with *Ch 4, 1.7 Visual and non-destructive examination 1.7.10* or *Ch 4, 1.7 Visual and non-destructive examination 1.7.11* respectively, on at least one casting from each cast or from every 400 castings, whichever is the lesser.

9.6 Repair of defects

9.6.1 Minor defects may be removed by grinding provided that the allowable minus tolerance is not exceeded.

9.6.2 Defects which exceed the allowable minus tolerance may be removed by grinding or chipping followed by welding, provided the weld depth does not exceed 40 per cent of the wall thickness and that the following requirements are met:

(a) welding is not to be carried out in the as-cast condition; the grain structure has to be refined by heat treatment,
(b) the casting is to be preheated to 80 - 100 °C,
(c) welding is to be performed only by qualified welders in accordance with a qualified welding procedure,
(d) all welded castings are to be post-weld heat treated at a temperature not less than 550°C,
(e) the welded areas are to be ground or machined flush with the adjacent surface and inspected by magnetic particle or dye penetrant examination as appropriate.

9.7 Identification

9.7.1 Each casting is to be clearly marked by the manufacturer with at least the following:

(a) manufacturer's name or trade mark,
(b) cast number or identification number which will enable the full history of the casting to be traced.

9.7.2 Where the casting has been inspected and found acceptable it is to be marked with the Surveyor's personal stamp.

9.7.3 The markings may be stamped or cast on the inner surface of the casting.

9.8 Certification of materials

9.8.1 For each consignment an LR certificate, *see Ch 1, 3.1 General*, is to be issued for castings made under LR survey or alternatively a manufacturer's certificate is to be issued containing at least the following:

(a) Purchaser's name and order number.
(b) Grade of steel.
(c) Drawing and/or specification number.
(d) Cast number and chemical composition.
(e) Details of the heat treatment.
(f) Number and weight of the castings.
(g) Results of inspections and mechanical tests.

See (*Ch 1, 3.1 General*), for manufacturers approved under a Quality Assurance Scheme.

Contents

Steel Forgings

Section

■ *Section 1* General requirements

1.1 Scope

1.1.1 This Section gives the general requirements for steel forgings intended for use in the construction of ships, other marine structures, machinery, boilers, pressure vessels and piping systems. These requirements are also applicable to rolled slabs and billets used as a substitute for forgings and to rolled bars used for the manufacture (by machining operations only) of shafts, bolts, studs and other components of similar shape.

1.1.2 When required by the relevant Rules dealing with design and construction, forgings are to be manufactured and tested in accordance with Chapters*Ch 1 General Requirements* and *Ch 2 Testing Procedures for Metallic Materials*, together with the general requirements given in this Section and the appropriate specific requirements given in Sections *Ch 5, 2 Forgings for ship and other structural applications*.

1.1.3 As an alternative to *Ch 5, 1.1 Scope 1.1.2*, steel forgings which comply with National or proprietary specifications may be accepted provided that these specifications give reasonable equivalence to the requirements of this Chapter or alternatively are approved for a specific application. Generally, survey and certification are to be carried out in accordance with the requirements of *Ch 1 General Requirements*.

1.1.4 Normalised forgings with mass up to 1000 kg each may be batch tested. A batch is to consist of forgings of similar shape and dimensions, made from the same steel-making heat, heat treated together and with a total mass not exceeding 6 tonnes.

1.1.5 Quenched and tempered forgings with mass up to 500 kg each may be batch tested. A batch is to consist of forgings of similar shape and dimensions, made from the same steel-making heat, heat treated together in the same furnace and with a total mass not exceeding 3 tonnes.

1.1.6 A batch testing procedure may also be used for hot rolled bars, *see Ch 5, 3.4 Mechanical tests 3.4.3*.

1.1.7 Where small forgings are produced in large quantities, or where forgings of the same type are produced in regular quantities, alternative survey procedures in accordance with *Ch 1, 2.4 Materials Quality Scheme* may be adopted.

1.2 Manufacture

1.2.1 Forgings are to be made at works which have been approved by Lloyd's Register (hereinafter referred to as LR). The steel used is to be manufactured in accordance with the requirements of *Ch 3, 1.4 Manufacture*.

1.2.2 When forgings are made directly from ingots, or from blooms or billets forged from ingots, the ingots are to be cast in chill moulds with the larger cross-section uppermost and with efficient feeder heads.

1.2.3 Adequate top and bottom discards are to be made to ensure freedom from piping and harmful segregations in the finished forgings.

1.2.4 The forgings are to be gradually and uniformly hot worked and are to be formed as closely as possible to the finished shape and size. The plastic deformation is to be such as to ensure soundness, uniformity of structure and satisfactory mechanical properties after heat treatment.

1.2.5 For certain components, such as crankshafts, where grain flow is required in the most favourable direction having regard to the mode of stressing in service, the proposed method of manufacture may require special approval by LR. In such cases, tests may be required to demonstrate that a satisfactory structure and grain flow are obtained.

1.2.6 The reduction ratio (reduction of area expressed as a ratio) is to be calculated with reference to the average cross-sectional area of the ingot or continuously cast material, where appropriate. Where an ingot is initially upset, this reference area may be taken as the average cross-sectional area after this operation.

1.2.7 For components forged directly from ingots or from forged blooms or billets, and in which the fibre deformation is mainly longitudinal, the reduction ratio is not to be less than 3:1.

1.2.8 For forgings made from rolled billets, or where fibre deformation has taken place in more than one direction, the reduction ratio is not to be less than 4:1.

1.2.9 Where rolled bars are used as a substitute for forgings and the requirements of *Ch 5, 1.2 Manufacture 1.2.2* are not complied with, the reduction ratio is to be not less than 6:1 unless otherwise accepted by the LR Surveyor.

1.2.10 Where the length of any section of a shaft forging is less than its diameter (e.g. a collar), the reduction ratio is to be not less than half that given in *Ch 5, 1.2 Manufacture 1.2.7*, *Ch 5, 1.2 Manufacture 1.2.8* or *Ch 5, 1.2 Manufacture 1.2.9* respectively.

1.2.11 Disc type forgings, such as gear wheels, are to be made by upsetting, and the thickness of any part of the disc is to be not more than one-half of the length of the billet from which it was formed, provided that this billet has received an initial forging reduction of not less than 1,5:1. Where the piece used has been cut directly from an ingot, or where the billet has received an initial reduction of less than 1,5:1, the thickness of any part of the disc is to be not more than one-third of the length of the original piece.

1.2.12 Rings and other types of hollow forgings are to be made from pieces cut from ingots or billets and which have been suitably punched, bored or trepanned prior to expanding or hollow forging. Alternatively, pieces from hollow cast ingots may be used. The wall thickness of the forging is to be not more than one-half of the thickness of the prepared hollow piece from which it was formed. Where this is not practicable, the forging procedure is to be such as to ensure that adequate work is given to the piece prior to punching, etc. This may be either longitudinal or upset working of not less than 2:1.

1.2.13 The shaping of forgings or rolled slabs and billets by flame cutting, scarfing or arc-air gouging is to be undertaken in accordance with recognised good practice and, unless otherwise approved, is to be carried out before the final heat treatment. Preheating is to be employed where necessitated by the composition and/or thickness of the steel. For certain components, subsequent machining of all flame cut surfaces may be required, *see Ch 5, 4.2 Manufacture 4.2.4*.

1.2.14 Where two or more forgings are joined by welding to form a composite component, details of the proposed welding procedure are to be submitted for approval. Welding approval procedure tests may be required.

1.3 Quality

1.3.1 All forgings are to be free from surface or internal defects which would be prejudicial to their proper application in service.

1.4 Chemical composition

1.4.1 All forgings are to be made from killed steels, and the chemical composition of ladle samples is to comply with the requirements detailed in subsequent Sections in this Chapter. Where general overall limits are specified, the chemical composition selected is to be appropriate for the type of steel, dimensions and required mechanical properties of the forgings being manufactured.

1.4.2 Except where otherwise specified, suitable grain refining elements such as aluminium, niobium or vanadium may be used at the discretion of the manufacturer. The content of such elements is to be reported in the ladle analysis.

1.4.3 For alloy steel forgings, the chemical composition of ladle samples is to generally comply with the following overall limits and the requirements of the approved specifications:

Carbon	0,45% max.
Silicon	0,45% max.
Manganese	0,30% min.

Sulphur	0,035% max.
Phosphorus	0,035% max.
Copper	0,30% max.

And at least one of the following elements to comply with the minimum content:

Chromium	0,40% min.
Molybdenum	0,15% min.
Nickel	0,40% min.

The contents of all alloying elements and significant impurities detailed in the specification are to be reported.

1.5 Heat treatment

1.5.1 At an appropriate stage of manufacture, after completion of all hot working operations, forgings are to be suitably heat treated to refine the grain structure and to obtain the required mechanical properties. Acceptable heat treatment procedures are to be such as to avoid the formation of hair-line cracks and are detailed in Sections *Ch 5, 2 Forgings for ship and other structural applications*.

1.5.2 Heat treatment is to be carried out in a properly constructed furnace which is efficiently maintained and has adequate means of temperature control. The furnace dimensions are to be such as to allow all the steel forgings to be uniformly heated to the necessary temperature. In the case of very large forgings, alternative methods of heat treatment will be specially considered. Sufficient thermocouples are to be connected to the steel forging(s) in the furnace to show that the temperature is adequately uniform and the temperatures are to be recorded throughout the heat treatment. Copies of these records are to be presented to the Surveyor together with a sketch showing the positions at which the temperature measurements were carried out. The records are to identify the furnace that was used and give details of the steel-making heat, the heat treatment temperature, time at temperature and the date. The Surveyor is to examine the charts and confirm the details on the certificate. Alternative procedures are to be approved by LR's Materials and NDE Department.

1.5.3 Where forgings are to be quenched and tempered and cannot be hot worked close to size and shape, they are to be suitably rough machined or flame cut prior to being subjected to this treatment.

1.5.4 If for any reason a forging is subsequently heated for further hot working, the forging is to be reheat treated.

1.5.5 If any straightening operation is performed after the final heat treatment, consideration should be given to a subsequent stress relieving heat treatment in order to avoid the possibility of harmful residual stresses.

1.5.6 Where it is intended to surface harden forgings, full details of the proposed procedure and specification are to be submitted for approval. For the purposes of this approval, the manufacturer will be required to demonstrate by tests that the proposed procedure gives a uniform surface layer of the required hardness and depth and that it does not impair the soundness and properties of the steel.

1.5.7 Where induction hardening or nitriding is to be carried out after machining, forgings are to be heat treated at an appropriate stage to a condition suitable for this subsequent surface hardening.

1.5.8 Where carburising is to be carried out after machining, forgings are to be heat treated at an appropriate stage (generally either by full annealing or by normalising and tempering) to a condition suitable for subsequent machining and carburising.

1.5.9 The forge is to maintain records of heat treatment identifying the furnace used, furnace charge, thermocouple location, date, temperature and time at temperature. The records are to be presented to the Surveyor on request.

1.6 Test material

1.6.1 Test material, sufficient for the required tests and for possible re-test purposes, is to be provided with a cross-sectional area of not less than that part of the forging which it represents. This test material is to be integral with each forging, except in the case of small forgings which are batch tested, *see Ch 5, 1.6 Test material 1.6.4*.

1.6.2 Where a forging is subsequently divided into a number of components, all of which are heat treated together in the same furnace, for test purposes this may be regarded as one forging and the number of tests required is to be related to the total length and mass of the original multiple forging, *see Ch 5, 2.4 Mechanical tests 2.4.2*.

1.6.3 Except for components which are to be carburised, test material is not to be cut from a forging until the heat treatment detailed in Sections *Ch 5, 2 Forgings for ship and other structural applications* has been completed. The testing procedure for components which are to be carburised is to be in accordance with the details given in *Ch 5, 5 Forgings for gearing*.

1.6.4 Where a number of small forgings of about the same size are made from one cast and heat treated together in the same furnace, batch testing procedures (*see Ch 5, 1.1 Scope 1.1.4*) may be adopted using one of the forgings for test purposes, or alternatively using separately forged test samples. These test samples are to have a forging reduction similar to that used for the forgings which they represent. They are to be properly identified and heat treated together with the forgings.

1.7 Mechanical tests

1.7.1 Specimens for mechanical tests are to be prepared as required by Sections *Ch 5, 2 Forgings for ship and other structural applications*.

1.7.2 Test specimens are normally to be cut with their axes either mainly parallel (longitudinal test) or mainly tangential (tangential test) to the principal axial direction of each product.

1.7.3 Unless otherwise agreed, the longitudinal axis of the test specimens is to be positioned as follows:

(a) for thickness or diameter ≤ 50 mm, the axis is to be at the mid-thickness or the centre of the cross section;
(b) for thickness or diameter > 50 mm, the axis is to be at one quarter thickness (mid-radius) or 80 mm, whichever is less, below any heat treated surface;

Test pieces shall be taken in such a way that no part of the gauge length is machined from material closer than 12,5 mm to any heat treated surface. For impact testing, this requirement is to apply to the complete test piece.

1.7.4 Tensile test specimens are to be machined to the dimensions detailed in *Ch 2 Testing Procedures for Metallic Materials*. Where this is precluded by the dimensions of the forging, the test specimen is to be of the largest practicable cross-sectional area.

1.7.5 Impact test specimens are to be prepared in accordance with the requirements of *Ch 2 Testing Procedures for Metallic Materials*.

1.7.6 The procedures used for the tensile and impact tests are to be in accordance with the requirements of *Ch 2 Testing Procedures for Metallic Materials*.

1.7.7 Hardness tests, preferably of the Brinell type, are to be carried out when specified in subsequent Sections in this Chapter.

1.8 Visual and non-destructive examination

1.8.1 Before acceptance, all forgings are to be presented to the Surveyor for visual examination. Where applicable, this is to include the examination of internal surfaces and bores.

1.8.2 Forgings are to be examined in the condition for final delivery. Surfaces are to be clean and free from dirt, grease, paint, etc. Black forgings are to be suitably descaled by either shotblasting or flame descaling methods.

1.8.3 All forgings are to be free of cracks, crack-like indications, laps, seams, folds, or other injurious indications. At the request of the Surveyor, additional magnetic particle, dye penetrant and ultrasonic testing may be required for a more detailed evaluation of surface irregularities.

1.8.4 When specified in subsequent Sections in this Chapter, or by an approved procedure for welding composite components, *see Ch 5, 1.2 Manufacture 1.2.14*, appropriate non-destructive examination is also to be carried out before acceptance. All tests are to be carried out in accordance with the requirements of *Ch 1, 5 Non-destructive examination*.

1.8.5 Magnetic particle and dye penetrant testing is to be carried out when the forgings are in the finished machined condition, *see also Ch 1, 2.3 Materials Survey Scheme 2.3.5*. For magnetic particle testing, attention is to be paid to the contact between the forging and the clamping devices of stationary magnetisation benches in order to avoid local overheating or burning damage on its surface. Prods are not permitted on finished machined items. Unless otherwise agreed, these tests are to be carried out in the presence of the Surveyor.

1.8.6 The following definitions apply to indications associated with magnetic particle and dye penetrant inspection:

(a) **Linear indication**. An indication in which the length is at least three times the width.
(b) **Nonlinear indication**. An indication of circular or elliptical shape with a length less than three times the width.
(c) **Aligned indication**. Three or more indications in a line, separated by 2 mm or less edge-to-edge.
(d) **Open indication**. An indication visible after removal of the magnetic particles or that can be detected by the use of contrast dye penetrant.

(e) **Non-open indication**. An indication that is not visually detectable after removal of the magnetic particles or that cannot be detected by the use of contrast dye penetrant.

(f) **Relevant indication**. An indication that is caused by a condition or type of discontinuity that requires evaluation. Only indications which have any dimension greater than 1,5 mm are to be considered relevant.

1.8.7 Acceptance standards for defects found by visual or non destructive examinations are to be in accordance with any specific requirements of the approved plan, and with equivalence to any additional requirements of this Chapter. In all cases they are to be to the satisfaction of the Surveyor.

1.8.8 Where required, ultrasonic examination is to be carried out after the forgings have been machined to a condition suitable for this type of examination and after the final heat treatment. Both radial and axial scanning are to be carried out where appropriate for the shape and the dimensions of the forgings being examined. Scanning is to take into account near surface examination. Unless otherwise agreed, examinations are to be carried out by the manufacturer, although Surveyors may request to be present in order to verify that the examination is being carried out in accordance with the agreed procedure.

1.8.9 If the forging is supplied in the black condition for machining at a separate works, the manufacturer is to ensure that a suitable ultrasonic examination is carried out to verify the internal quality of the forging.

1.8.10 In the circumstance detailed in either *Ch 5, 1.8 Visual and non-destructive examination 1.8.8* or *Ch 5, 1.8 Visual and non-destructive examination 1.8.9*, the manufacturer is to provide the Surveyor with a signed report confirming that ultrasonic examination has been carried out and that such inspection has not revealed any significant internal defects.

1.8.11 Unless otherwise agreed, the accuracy and verification of dimensions are the responsibility of the manufacturer.

1.8.12 In the event of any forging proving defective during subsequent machining or testing, it is to be rejected notwithstanding any previous certification.

1.8.13 When required by the conditions of approval for surface hardened forgings (*see Ch 5, 1.5 Heat treatment 1.5.6*) additional test samples are to be processed at the same time as the forgings which they represent. These test samples are subsequently to be sectioned in order to determine the hardness, shape and depth of the locally hardened zone and which are to comply with the requirements of the approved specification.

1.9 Rectification of defects

1.9.1 Small surface imperfections may be removed by grinding or by chipping and grinding. Complete elimination of these imperfections is to be proved by magnetic particle or dye penetrant examination (as appropriate to the material). At the discretion of the Surveyor, the resulting shallow grooves or depressions can be accepted, provided that they are blended by grinding.

1.9.2 Repairs by welding are not generally permitted, but special consideration will be given to such repairs where they are of a minor nature and in areas of low working stresses. In such cases, full details of the proposed repair and subsequent inspection procedures are to be submitted for review by the Surveyors prior to the commencement of the proposed rectification. A report and/or sketch detailing the extent and location of all repairs, together with details of the post-weld heat treatment and non-destructive examination are to be provided for record purposes and are to be attached to the certificate.

1.9.3 Repair welding is not permitted for crankshafts or similar rotating components.

1.9.4 Where fabrication welding is involved, *see Ch 5, 1.2 Manufacture 1.2.14*, any repair of defects is to be carried out in accordance with the approved welding procedure.

1.9.5 The forging manufacturer is to maintain records of repairs and subsequent inspections traceable to each forging. The records are to be presented to the Surveyor on request.

1.9.6 Non-open indications evaluated as segregation are acceptable.

1.10 Identification

1.10.1 The manufacturer is to adopt a system of identification, which will enable all finished forgings to be traced to the original cast, forging process and heat treatment batch, and the Surveyor is to be given full facilities for so tracing the castings when required.

1.10.2 Forgings are to be clearly marked by the manufacturer in accordance with the requirements of *Ch 1 General Requirements*. The following details are to be shown on all forgings which have been accepted:

(a) Identification number, cast number or other marking which will enable the full history of the forging to be traced.

(b) LR or Lloyd's Register and the abbreviated name of LR's local office.

(c) Personal stamp of Surveyor responsible for inspection.

(d) Test pressure, where applicable.
(e) Date of final inspection.

1.10.3 Modified arrangements for the identification of small forgings manufactured in large numbers, as with closed-die forgings may be agreed with the Surveyor.

1.11 Certification of materials

1.11.1 A LR certificate is to be issued, *see Ch 1, 3.1 General*.

1.11.2 The manufacturer is to provide the Surveyor with a written statement giving the following particulars for each forging or batch of forgings which has been accepted:

(a) Purchaser's name and order number.
(b) Description of forgings and steel quality.
(c) Identification number.
(d) Steel-making process, cast number and chemical analysis of ladle samples.
(e) General details of heat treatment.
(f) Results of mechanical tests.
(g) Test pressure, where applicable.

1.11.3 As a minimum, the chemical composition of ladle samples is to include the content of all the elements detailed in the specific requirements.

1.11.4 Where applicable, the manufacturer is also to provide a signed report regarding ultrasonic examination as required by *Ch 5, 1.8 Visual and non-destructive examination 1.8.8*, a report of magnetic particle inspection and a statement and/or sketch detailing all repairs by welding as required by *Ch 5, 1.9 Rectification of defects 1.9.2*.

1.11.5 When steel is not produced at the works at which it is forged, a certificate is to be supplied by the steelmaker stating the process of manufacture, cast number and the chemical composition of ladle samples. The works at which the steel was produced is to have been approved by LR, *see Ch 5, 1.4 Chemical composition 1.4.3*.

■ *Section 2*
Forgings for ship and other structural applications

2.1 Scope

2.1.1 This Section gives the specific requirements for carbon-manganese steel forgings intended for ship and other structural applications such as rudder stocks, pintles, etc.

2.1.2 Where it is proposed to use an alloy steel, particulars of the chemical composition, mechanical properties and heat treatment are to be submitted for approval, *see Ch 5, 1.4 Chemical composition 1.4.3*.

2.2 Chemical composition

2.2.1 For forgings to which structural items are to be attached by welding or which are intended for parts of a fabricated component, or are to be weld cladded or may be subject to weld repair in service, the chemical composition of ladle samples is to comply with the following:

Carbon	0,23% max.
Silicon	0,45% max.
Manganese	0,30–1,50% but not less than 3 times the actual carbon content for components which are not given a post-weld heat treatment
Sulphur	0,035% max.
Phosphorus	0,035% max.
Residual elements:	

Copper	0,30% max.
Chromium	0,30% max.
Molybdenum	0,15% max.
Nickel	0,40% max.
Total	0,85% max.

For samples from forgings, the carbon content is not to exceed 0,26 per cent.

2.2.2 It is recommended that forgings for rudder stocks, pintles and rudder coupling bolts comply with *Ch 5, 2.2 Chemical composition 2.2.1* in order to obtain satisfactory weldability for any future repairs by welding in service.

2.2.3 For forgings not intended for welding the carbon content may be 0,65per cent max., *see Ch 5, 3.2 Chemical composition 3.2.1*.

2.3 Heat treatment

2.3.1 Carbon-manganese steel forgings are to be:

(a) fully annealed; or
(b) normalised; or
(c) normalised and tempered at a temperature of not less than 550°C.
(d) quenched and tempered.

2.3.2 Alloy steel forgings are to be quenched and then tempered at a temperature of not less than 550°C. Alternatively, they may be supplied in the normalised and tempered condition, in which case the specified mechanical properties are to be agreed by LR.

2.4 Mechanical tests

2.4.1 At least one tensile specimen is to be taken from each forging or batch of forgings.

2.4.2 Where a forging exceeds both 4 tonnes in mass and 3 m in length, tensile test specimens are to be taken from each end. These limits refer to the `as forged' mass and length but exclude the test material.

2.4.3 Unless otherwise agreed between the manufacturer and the Surveyor, the test specimens are to be cut in a longitudinal direction.

2.4.4 The results of all tensile tests are to comply with the requirements given in *Table 5.2.1 Mechanical properties for ship and other structural applications* appropriate to the specified minimum tensile strength. Forgings may be supplied to any specified minimum tensile strength within the general limits given in *Table 5.2.1 Mechanical properties for ship and other structural applications*, and intermediate values may be obtained by interpolation. *See Ch 5, 2.4 Mechanical tests 2.4.6* for rudder stocks, pintles, and rudder coupling keys and bolts.

2.4.5 For large forgings, where tensile tests are taken from each end, the variation in tensile strength is not to exceed 70 N/mm^2.

2.4.6 For rudder stocks, pintles, and rudder coupling keys and bolts, the minimum specified yield strength is not to be less than 200 N/mm^2, *see Table 13.2.1 Rudder material factor, k*.

Table 5.2.1 Mechanical properties for ship and other structural applications

Steel type	Yield stress N/mm^2 minimum	Tensile strength N/mm^2	Elongation on 5,65 $\sqrt{S_0}$ min. %		Reduction of area min. %	
			Long.	Tang.	Long.	Tang.
C and C-Mn	180	360-480	28	20	50	35
	200	400-520	26	19	50	35
	220	440-560	24	18	50	35
	235	470-590	23	17	45	35
	240	480-600	22	16	45	30
	260	520-640	21	15	45	30
	280	560-680	20	14	40	27
	300	600-750	18	13	40	27
	320	640-790	17	12	40	27
	340	680-830	16	12	35	24
	360	720-870	15	11	35	24
	380	760-910	14	10	35	24
Alloy	350	550-700	20	14	50	35
	400	600-750	18	13	50	35
	450	650-800	17	12	50	35

2.4.7 Impact tests are required for rudder stocks to be fitted to vessels which have an ice class notation. The tests are to be carried out at minus 10°C and the average energy value is to be not less than 27J.

2.5 Non-destructive examination

2.5.1 Surface inspections are to be carried out by visual examination and magnetic particle testing (or dye penetrant testing where appropriate).

2.5.2 Surface inspections are to be carried out in the zones I and II as indicated in *Figure 5.2.1 Inspection zones for magnetic particle/dye penetrant testing on rudder stocks*.

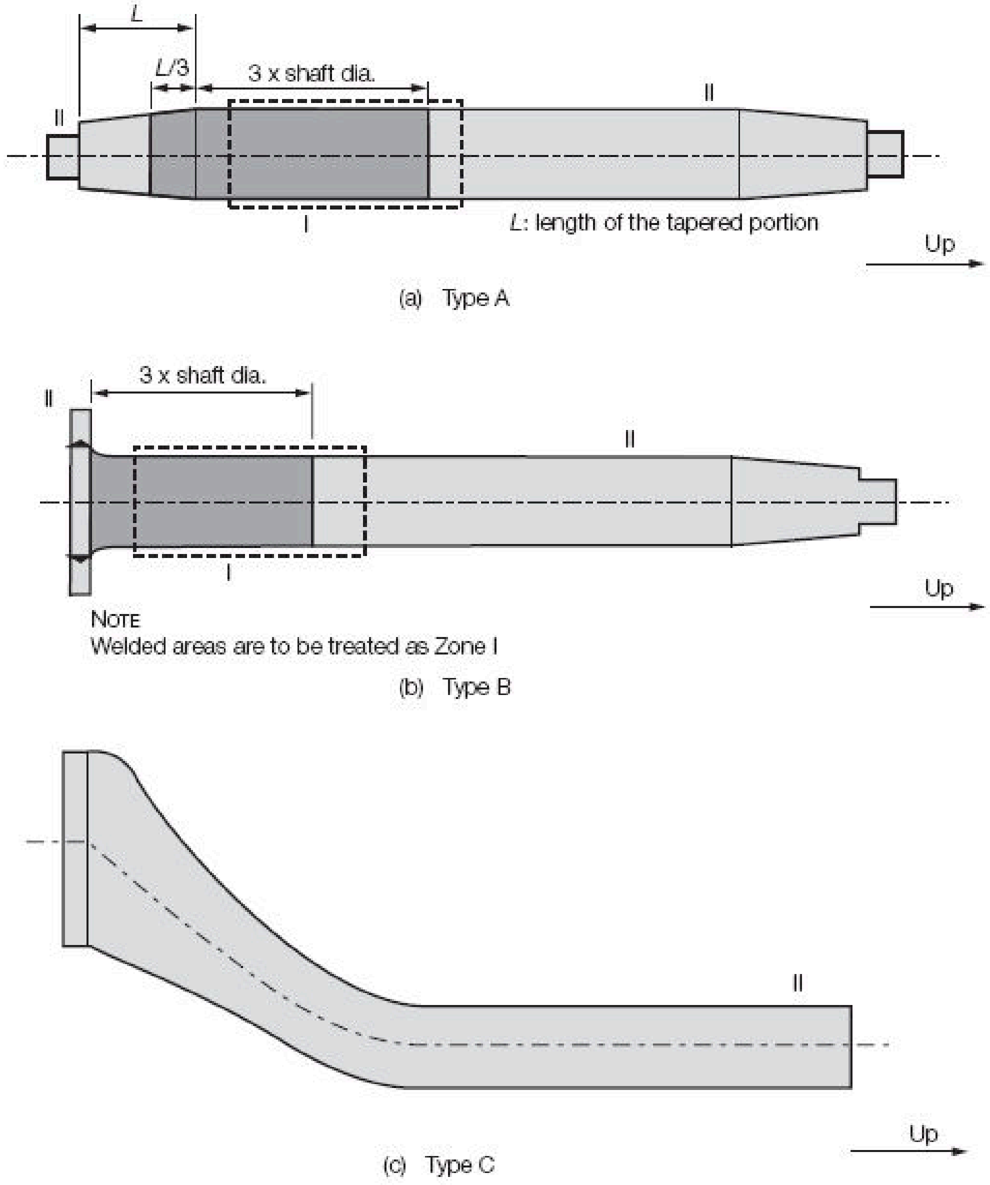


Figure 5.2.1 Inspection zones for magnetic particle/dye penetrant testing on rudder stocks

2.5.3 For the purpose of evaluating indications, the surface is to be divided into reference areas of 225 cm^2. The area is to be taken in the most unfavourable location relative to the indication being evaluated.

2.5.4 The allowable number and size of indications in the reference area is given in *Table 5.2.2 Steel forgings surface inspection*.

Table 5.2.2 Steel forgings surface inspection

Inspection zone	Maximum number of indications	Type of indication	Maximum number each type	Maximum dimension, mm
I	3	Linear	0, *see* Note	–
		Non-linear	3	3,0
		Aligned	0, *see* Note	–
II	10	Linear	3, *see* Note	3,0
		Non-linear	7	5,0
		Aligned	3, *see* Note	3,0

Note Linear or aligned indications are not permitted on bolts, which receive a direct fluctuating load, e.g. main bearing bolts, connecting rod bolts, crosshead bearing bolts and cylinder cover bolts.

2.5.5 Volumetric inspection is to be carried out by ultrasonic testing using the contact method.

2.5.6 Ultrasonic testing is to be carried out on rudder stocks having a finished diameter of 200 mm or greater.

2.5.7 Ultrasonic testing is to be carried out in the zones II and III as indicated in *Figure 5.2.2 Inspection zones for ultrasonic testing on rudder stocks*. Areas may be upgraded to a higher zone at the discretion of the Surveyor.

2.5.8 Ultrasonic acceptance criteria are shown in *Table 5.3.3 Acceptance criteria for ultrasonic testing*, alternatively *see Ch 1, 5 Non-destructive examination*.

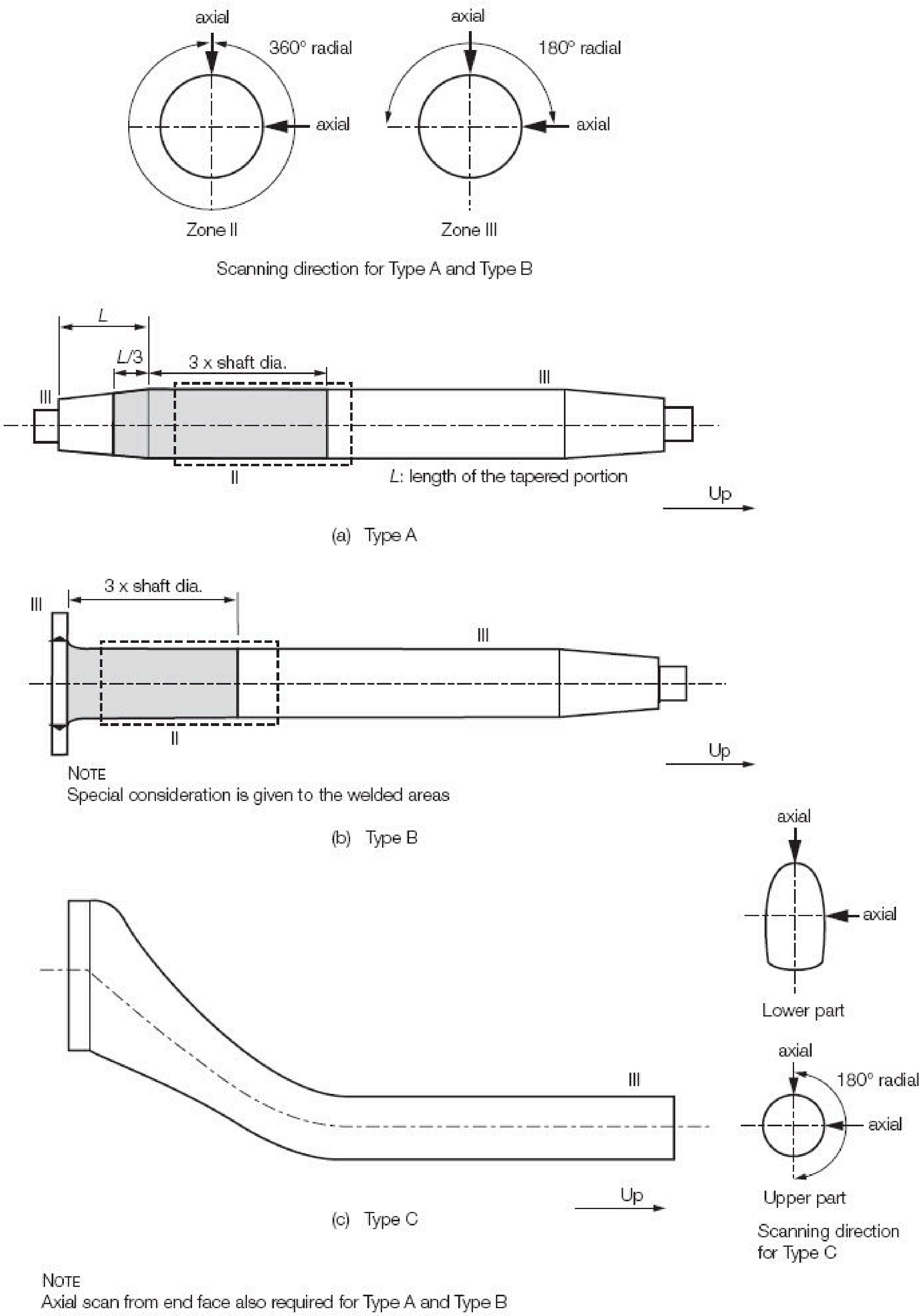


Figure 5.2.2 Inspection zones for ultrasonic testing on rudder stocks

■ *Section 3*
Forgings for shafting and machinery

3.1 Scope

3.1.1 Detailed in this Section are the requirements for carbon-manganese steel forgings for shafting and other items of machinery which are not within the scope of Sections *Ch 5, 4 Forgings for crankshafts*.

3.1.2 Where it is proposed to use alloy steel forgings, particulars of the chemical composition, mechanical properties and heat treatment are to be submitted for approval. For main propulsion shafting in alloy steels, the specified minimum tensile strength is not to exceed 800 N/mm^2 (800–950 N/mm^2 acceptance range) and for other forgings is not to exceed 1100 N/mm^2 (1100–1300 N/mm^2 acceptance range).

3.2 Chemical composition

3.2.1 The chemical composition of ladle samples for carbon and carbon-manganese steels is to comply with the following overall limits:

Carbon	0,65% max.
Silicon	0,45% max.
Manganese	0,30- 1,50%
Sulphur	0,035% max.
Phosphorus	0,035% max.
Residual elements:	
Copper	0,30% max.
Chromium	0,30% max.
Molybdenum	0,15% max.
Nickel	0,40% max.
Total	0,85% max.

3.2.2 For alloy steels, *see Ch 5, 1.4 Chemical composition 1.4.3*.

3.2.3 For forgings to which structural items are to be attached by welding, or which are intended for parts of a fabricated component, are to be of weldable quality, *see Ch 5, 2.2 Chemical composition 2.2.1*.

3.3 Heat treatment

3.3.1 Forgings are to be:

(a) fully annealed; or
(b) normalised; or
(c) normalised and tempered; or
(d) quenched and tempered.

The tempering temperature is to be not less than 550°C.

3.4 Mechanical tests

3.4.1 At least one tensile test is to be made on each forging, or each batch of forgings. Impact tests are not required except on screwshafts for ice service, *see Ch 5, 3.4 Mechanical tests 3.4.12*.

3.4.2 Where a forging exceeds both 4 tonnes in mass and 3 m in length, a tensile test is to be taken from each end. These limits refer to the `as forged' mass and length but exclude the test material.

3.4.3 A batch testing procedure may be used for hot rolled bars not exceeding 250 mm diameter, which are intended for the manufacture (by machining operations only) of straight shafting, bolts, studs and other machinery components of similar shape. A batch is to consist of either:

(a) material from the same piece provided that, where this is cut into individual lengths, these are all heat treated together in the same furnace, or

(b) bars of the same diameter and cast, heat treated together in the same furnace and with a total mass not exceeding 2,5 tonnes.

3.4.4 The test specimens are to be taken in the longitudinal direction but, at the discretion of the manufacturer and if agreed by the Surveyor, alternative directions or positions as shown in Figs. *Figure 5.3.1 Directions and positions of test specimens*, *Figure 5.3.2 Directions and positions of test specimens*, and *Figure 5.3.3 Directions and positions of test specimens* may be used.

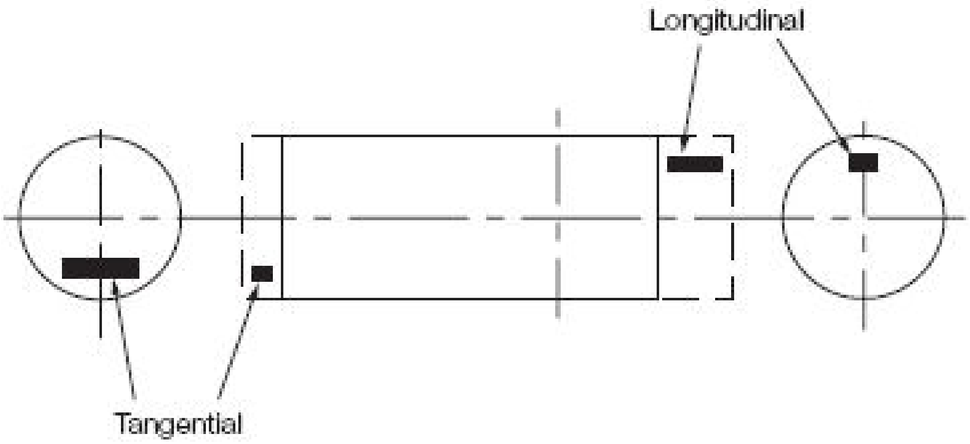


Figure 5.3.1 Directions and positions of test specimens

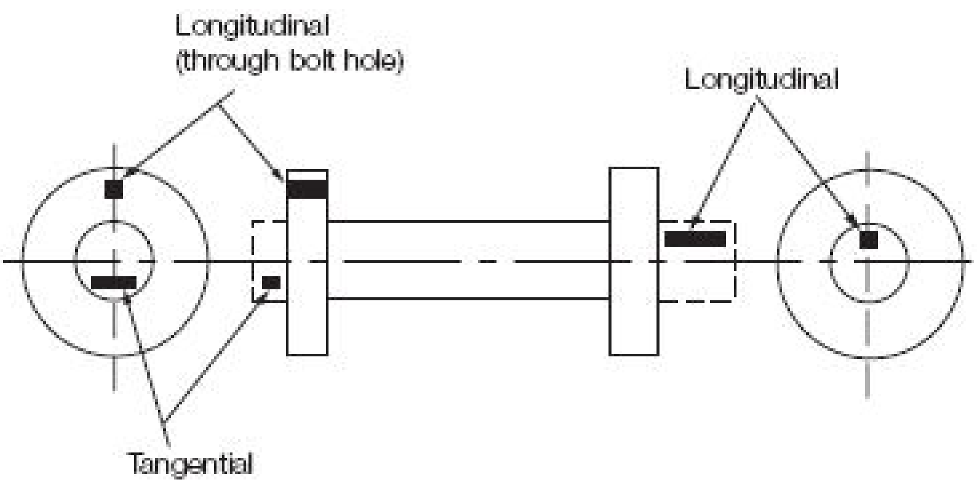


Figure 5.3.2 Directions and positions of test specimens

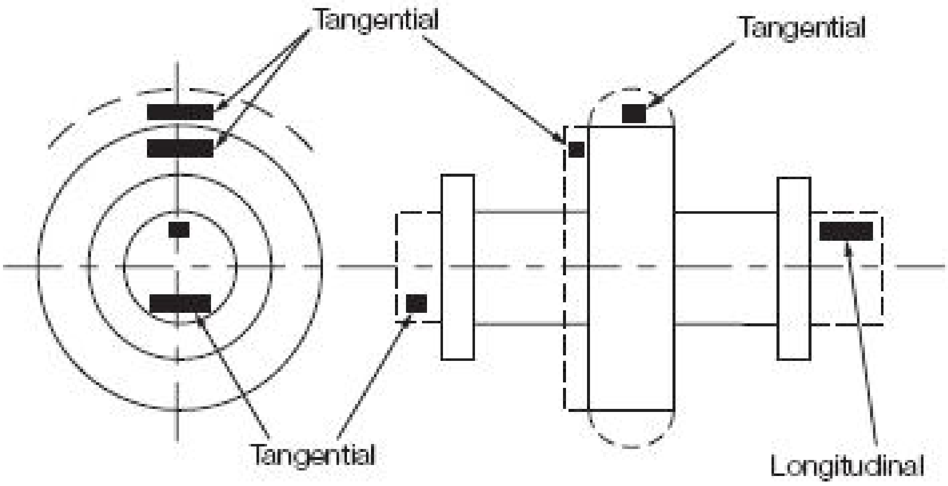


Figure 5.3.3 Directions and positions of test specimens

3.4.5 For carbon-manganese steels, *Table 5.3.1 Mechanical properties for acceptance purposes: carbon and carbon-manganese steel forgings for machinery and shafting* gives the minimum requirements for yield stress, elongation and reduction of area, corresponding to different strength levels, but it is not intended that these should necessarily be regarded as specific grades. Intermediate values for other specified minimum tensile strengths should be calculated by interpolation.

3.4.6 Forgings may be supplied to any specified minimum tensile strength selected within the general limits detailed in *Table 5.3.1 Mechanical properties for acceptance purposes: carbon and carbon-manganese steel forgings for machinery and shafting*, except that for main propulsion shafting forgings the specified minimum tensile strength is to be not less than 400 N/mm^2 (400–520 N/mm^2 acceptance range) and not greater than 600 N/mm^2 (600–750 N/mm^2 acceptance range) *see Table 5.3.1 Mechanical properties for acceptance purposes: carbon and carbon-manganese steel forgings for machinery and shafting*.

Table 5.3.1 Mechanical properties for acceptance purposes: carbon and carbon-manganese steel forgings for machinery and shafting

Tensile strength N/mm^2		Yield stress N/mm^2	Elongation on $5,65\sqrt{S_0}$ min %		Reduction of area min. %	
			Long.	Tang.	Long.	Tang.
360 – 480		180	28	20	50	35
400 – 520	*See* Note 1	200	26	19	50	35
440 – 560		220	24	18	50	35
470 – 590		235	23	17	45	35
480 – 600		240	22	16	45	30
520 – 640		260	21	15	45	30
560 – 680		280	20	14	40	27
600 – 750		300	18	13	40	27
640 – 790		320	17	12	40	27
680 – 830		340	16	12	35	24

700 – 850	*See* Note 2	350	15	11	35	24
720 – 870		360	15	11	35	24
760 – 910		380	14	10	35	24

Note 1. For main propulsion shafting forgings, the specified minimum tensile strength is to be between 400 and 600 N/mm^2 *see Ch 5, 3.4 Mechanical tests 3.4.6*.

Note 2. Where the specified minimum tensile strength exceeds 700 N/mm^2, forgings are to be supplied only in the quenched and tempered condition.

3.4.7 The results of all tensile tests are to comply with the requirements given in *Table 5.3.1 Mechanical properties for acceptance purposes: carbon and carbon-manganese steel forgings for machinery and shafting* appropriate to the specified minimum tensile strength.

3.4.8 The minimum requirements for yield stress, elongation and reduction of area, corresponding to different strength levels in alloy steel forgings are given in *Table 5.3.2 Mechanical properties for acceptance purposes: alloy steel forgings for machinery and shafting*.

Table 5.3.2 Mechanical properties for acceptance purposes: alloy steel forgings for machinery and shafting

Tensile strength N/mm^2		Yield stress N/mm^2	Elongation on 5,65 $\sqrt{S_0}$ min %		Reduction of area min. %	
			Long.	Tang.	Long.	Tang.
600 – 750	*See* Note	420	18	14	50	35
650 – 800		450	17	13	50	35
700 – 850		480	16	12	45	30
750 – 900		530	15	11	45	30
800 – 950		580	14	10	40	27
850 – 1000		630	13	9	40	27
900 – 1100		690	13	9	40	27
950 – 1150		750	12	8	35	24
1000 – 1200		810	12	8	35	24
1050 – 1250		870	11	7	35	24
1100 – 1300		930	11	7	35	24

Note For main propulsion shafting forgings, the minimum specified tensile strength is not to exceed 800 N/mm^2 *see Ch 5, 3.4 Mechanical tests 3.4.9* .

3.4.9 Forgings in alloy steels may be supplied to any specified minimum tensile strength selected within the general limits detailed in *Table 5.3.2 Mechanical properties for acceptance purposes: alloy steel forgings for machinery and shafting*, and minimum yield stress, elongation and reduction of area, obtained by interpolation, except that for main propulsion shafting forgings the specified minimum tensile strength is not to exceed 800 N/mm^2 (800-950 N/mm^2 acceptance range) *see Table 5.3.2 Mechanical properties for acceptance purposes: alloy steel forgings for machinery and shafting*.

3.4.10 The results of all tensile tests are to comply with the requirements given in *Table 5.3.2 Mechanical properties for acceptance purposes: alloy steel forgings for machinery and shafting* appropriate to the specified minimum tensile strength.

3.4.11 Where more than one tensile test is taken from a forging, the variation in tensile strength is not to exceed the following:

Specified minimum tensile strength N/mm^2	Difference in tensile strength N/mm^2
<600	70
≥600 <900	100
≥900	120

3.4.12 For screwshafts intended for ships with the notation **Ice Class 1AS** or **1A** and where the connection between the propeller and the screwshaft is by means of a key, a set of three Charpy V-notch impact tests (longitudinal test) is to be made on material from the propeller end of each shaft. The tests are to be carried out at –10°C and the average energy value is to be not less than 20 J.

3.5 Non-destructive examination

3.5.1 Magnetic particle or penetrant testing (where appropriate) is to be carried out on forgings for main propulsion shafting (including propeller shafts, intermediate shafts, and thrust shafts with minimum diameter not less than 100 mm), on all connecting rod and tie rod forgings and on the following components:

Cylinder heads (when intended for engines having a bore diameter larger than 300 mm)

Piston crowns (when intended for engines having a bore diameter larger than 400 mm)

Piston rods (when intended for engines having a bore diameter larger than 400 mm)

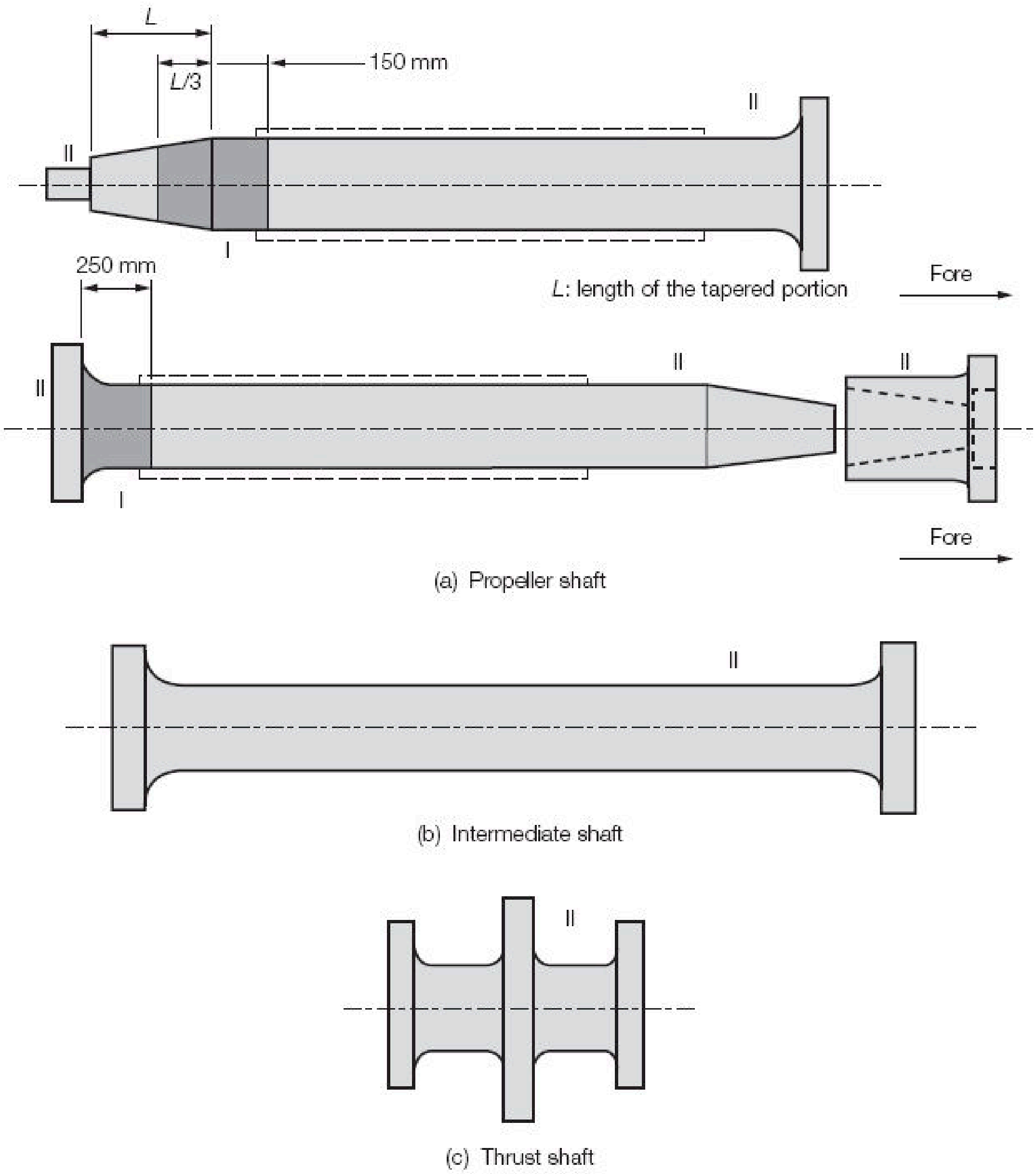
Turbocharger shaft and rotor (when required by the relevant Rules dealing with engine design and construction)

When intended for engines having a bore diameter larger than 300 mm, bolts and studs for:

- Cylinder heads
- Crossheads
- Connecting rod bearings
- Main bearings
- Crankshafts
- Tie rods
- Holding down bolts
- Propeller blades
- Propeller bosses

Regardless of the above , bolts and studs which are subjected to dynamic loading (for example, but not limited to, cylinder head bolts, tie rods, crankpin bolts, main bearing bolts, engine holding down bolts, propeller blade fastening bolts) and have a diameter of 50mm or greater are to be subjected to surface examinations.

3.5.2 The areas to be tested by magnetic particle or dye penetrant testing are shown in *Figure 5.3.4 Zones for magnetic particle/dye penetrant testing on machinery components* and *Figure 5.3.5 Zones for magnetic particle/dye penetrant testing on machinery components*. Areas of other components not shown in these figures are to be agreed with the Surveyor. For tie rods, only threaded portions and the adjacent material over a length equal to that of the thread need be tested.



NOTE
For propeller shaft, intermediate shafts and thrust shafts, all areas with stress raisers such as radial holes, slots and key ways are to be treated as Zone I.

Figure 5.3.4 Zones for magnetic particle/dye penetrant testing on machinery components

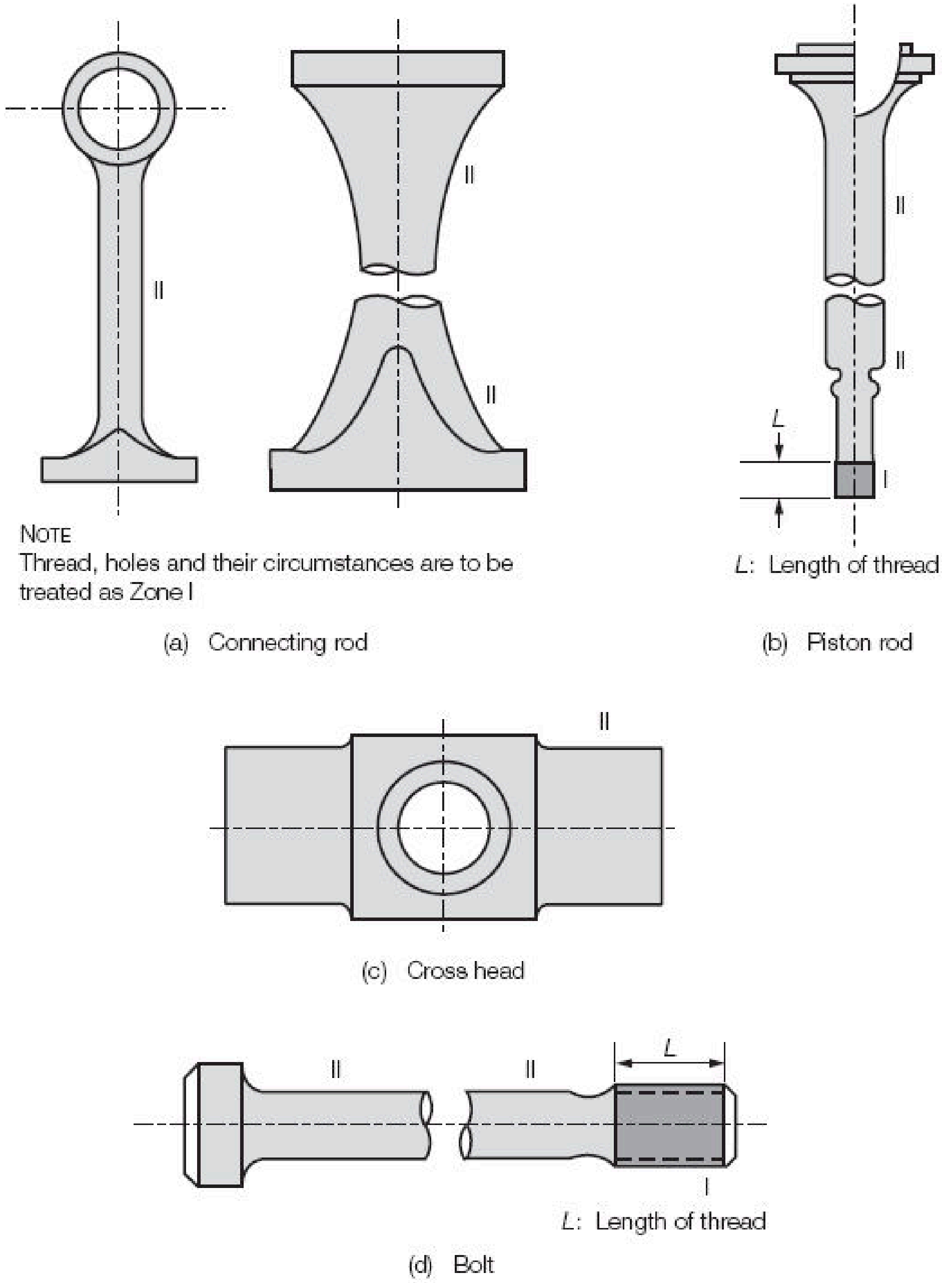


Figure 5.3.5 Zones for magnetic particle/dye penetrant testing on machinery components

3.5.3 Surface inspection acceptance criteria are to be in accordance with *Ch 5, 2.5 Non-destructive examination*. Other acceptance criteria may be applied, providing they meet these minimum criteria, and are to the satisfaction of the Surveyor.

3.5.4 Ultrasonic testing is to be carried out in accordance with *Ch 5, 2.5 Non-destructive examination* on the following items unless otherwise agreed with LR:

(a) Shafts having a finished diameter of 200 mm or larger when intended for main propulsion or other essential services.
(b) All piston crowns
(c) All cylinder heads.
(d) Piston rods for engines having a bore diameter greater than 400 mm.

(e) Connecting rods

(f) Turbocharger shaft and rotor (when required by the relevant Rules dealing with design and construction).

(g) Bolts and studs (as listed in *Ch 5, 3.5 Non-destructive examination 3.5.1*) for engines having a bore diameter greater than 300 mm.

The areas to be tested are shown in *Figure 5.3.6 Zones for ultrasonic testing on shafts* and *Figure 5.3.7 Zones for ultrasonic testing on machinery components*. Areas of other components not shown in these drawings are to be agreed with the Surveyor.

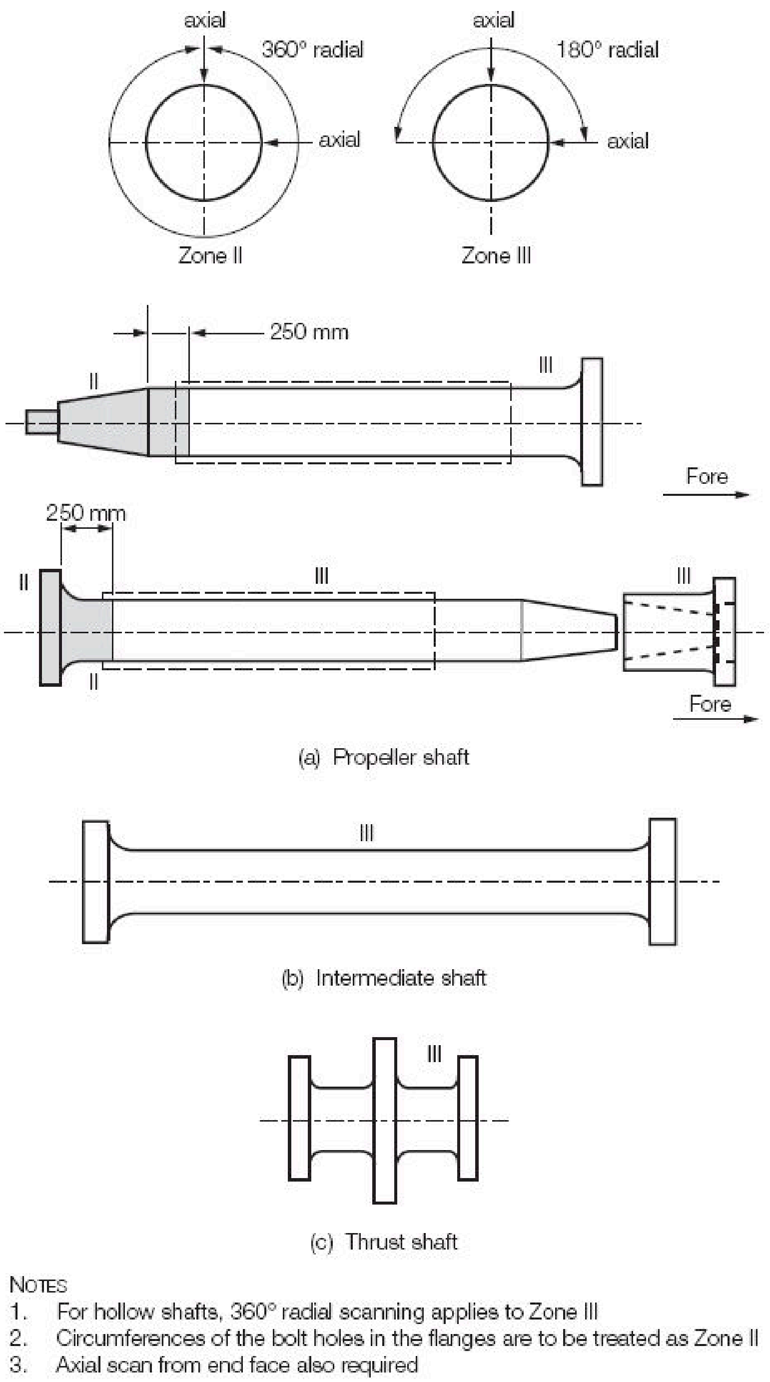


Figure 5.3.6 Zones for ultrasonic testing on shafts

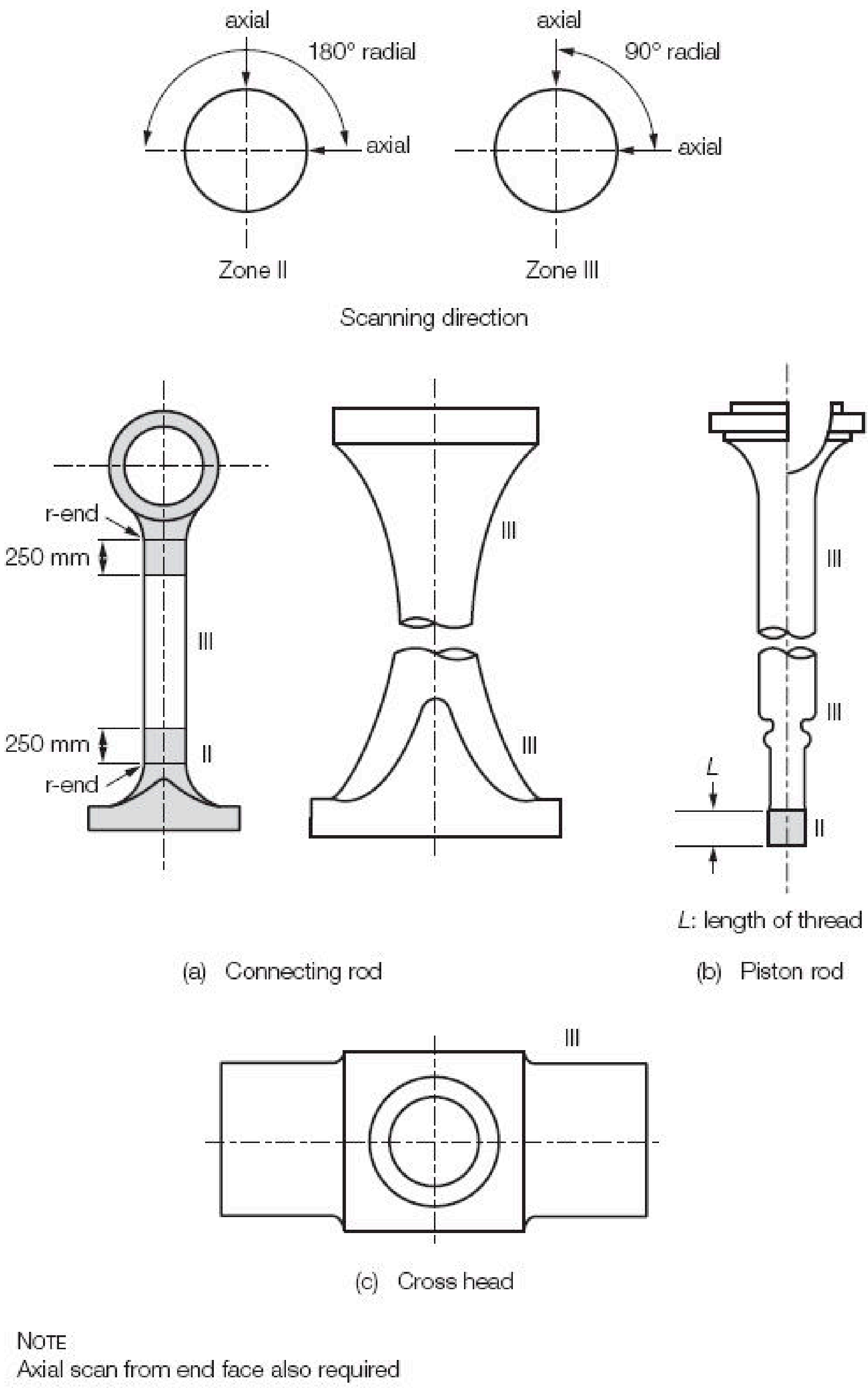


Figure 5.3.7 Zones for ultrasonic testing on machinery components

3.5.5 Ultrasonic acceptance criteria are shown in *Table 5.3.3 Acceptance criteria for ultrasonic testing*. Other acceptance criteria may be applied, providing they meet these minimum criteria, and are to the satisfaction of the Surveyor.

Table 5.3.3 Acceptance criteria for ultrasonic testing

Type of forging	Zone	Allowable disc shape according to Distance Gain Size (DGS), *see* Note 1, mm		Allowable length of indication, mm *see* Note 2
Propeller shaft	II	Outer	$d \le 2$	≤10
Intermediate shaft		Inner	$d \le 4$	≤15
Thrust shaft	III	Outer	$d \le 3$	≤10
Rudder stock		Inner	$d \le 6$	≤15
Connecting rod	II	$d \le 2$		≤10
Piston rod	III	$d \le 4$		≤10

Note 1. Outer part means the part beyond one third of the shaft radius from the centre. The inner part means the remaining core area.

Note 2. For accumulations of two or more isolated indications which are subjected to registration, the minimum distance between two neighbouring indications is to be at least the length of the larger indication.

■ *Section 4*
Forgings for crankshafts

4.1 Scope

4.1.1 The specific requirements for solid forged crankshafts and forgings for use in the construction of fully built and semi-built crankshafts are detailed in this Section.

4.1.2 Where it is proposed to use alloy steel forgings, particulars of the chemical composition (*see Ch 5, 1.4 Chemical composition 1.4.3*), heat treatment and mechanical properties are to be submitted for approval. The specified minimum tensile strength is not to exceed 1000 N/mm^2 (1000–1200 N/mm^2 acceptance range).

4.2 Manufacture

4.2.1 For closed die and continuous grain flow crankshafts forgings, where an allowance is given for design purposes, full details of the proposed method of manufacture are to be submitted for approval. In such cases, tests will be required to demonstrate that a satisfactory structure and grain flow are obtained. The number and positions of test specimens are to be agreed with LR.

4.2.2 For the manufacture of welded crankshafts, approval is required for the welding procedure.

4.2.3 For combined crankweb and pin forgings, the proposed method of forging is to be submitted for approval. It is recommended that these forgings be made by a folding method. Other methods which can be shown to produce sound forgings with satisfactory mechanical properties will be considered, but where the gapping method is used for cranks having a pin diameter exceeding 510 mm this will only be accepted provided that an upsetting operation is included in the manufacturing sequence. In general, the amount of work during the upsetting operation is to be such that the reduction in the original length of the ingot (after discard) or bloom is not less than 50 per cent.

4.2.4 Where crankwebs are flame cut from forged or rolled slabs, the procedure used is to be in accordance with *Ch 5, 1.2 Manufacture 1.2.13*, and additionally, unless specially agreed, a depth of at least 7,5 mm is to be removed by machining from all flame-cut surfaces.

4.3 Chemical composition

4.3.1 The chemical composition of ladle samples is to comply with *Ch 5, 3.2 Chemical composition 3.2.1* for carbon and carbon-manganese steels and *Ch 5, 1.4 Chemical composition 1.4.3* for alloy steels.

4.3.2 For alloy steel forgings which are to be nitrided, the phosphorus or sulphur contents are not to exceed 0,02 per cent.

4.4 Heat treatment

4.4.1 For forgings in all types of steels, heat treatment is to be either:

(a) normalising and tempering, or
(b) quenching and tempering.

The temperature used for tempering is to be not less than 550°C.

4.4.2 Where it is proposed to surface harden crankshaft forgings by nitriding or induction hardening, full details of the proposed procedure are to be submitted as required by *Ch 5, 1.5 Heat treatment 1.5.6*.

4.5 Mechanical tests

4.5.1 At least one tensile test specimen is to be taken from each forging.

4.5.2 For solid forged crankshafts, tests are to be taken in the longitudinal direction from the coupling end of each forging (test position A in *Figure 5.4.1 Solid forged crankshaft*). Where the mass, as heat treated but excluding test material, exceeds 3 tonnes, a second set of tests is to be taken from the end opposite the coupling, in addition (test position B in *Figure 5.4.1 Solid forged crankshaft*). Where the crankthrows are formed by machining or flame cutting, the second set of tests is to be taken in a tangential direction from material removed from the crankthrow at the end opposite the coupling (test position C in *Figure 5.4.1 Solid forged crankshaft*). For continuous grain flow (CGF) crankshaft forgings, where insufficient material exists for a second longitudinal test, the second set of tests may be taken in a tangential direction from the crankthrow (test position C in *Figure 5.4.2 CGF Crankshaft*).

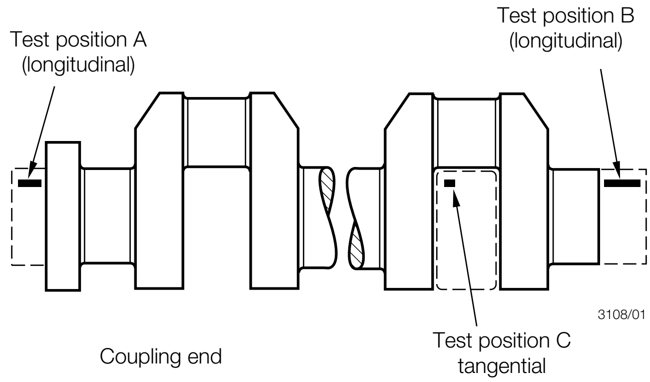


Figure 5.4.1 Solid forged crankshaft

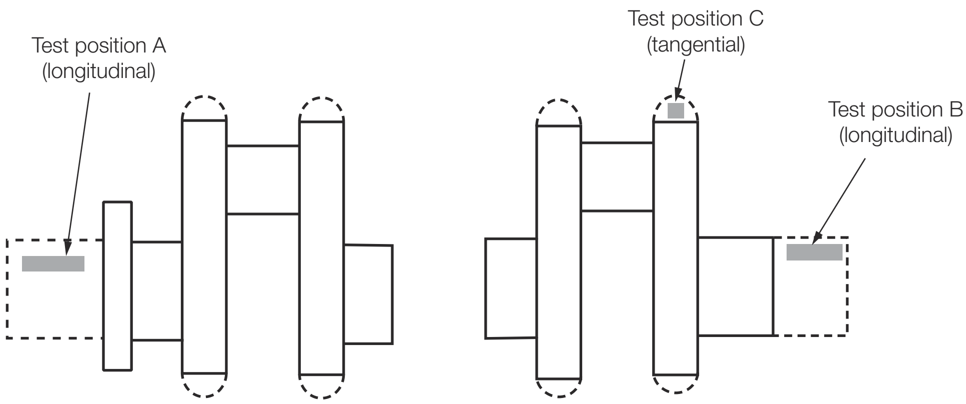


Figure 5.4.2 CGF Crankshaft

4.5.3 The number and position of test specimens from combined crankweb and pin forgings are to be in accordance with the requirements of the approved method of manufacture.

4.5.4 For other crankshaft forgings, tests are to be taken as detailed in *Ch 5, 3 Forgings for shafting and machinery*, except that for crankwebs the test specimens are to be cut in a tangential direction.

4.5.5 As an alternative to *Ch 5, 4.5 Mechanical tests 4.5.2*, small solid forged crankshafts may be batch tested in accordance with *Ch 5, 1.6 Test material 1.6.4*, provided that, in addition, hardness tests are carried out on each forging.

4.5.6 *Table 5.4.1 Mechanical properties for acceptance purposes: carbon-manganese steel forgings for crankshafts* to *Table 5.4.3 Mechanical properties for acceptance purposes: alloy steel forgings for crankshafts - Quenched and tempered* give the minimum requirements for yield stress and elongation corresponding to different strength levels, but it is not intended that these should necessarily be regarded as specific grades. The strength levels have been given in multiples of 40 N/mm^2, or 50 N/mm^2 in the case of alloy steels, to facilitate interpolation for intermediate values of specified minimum tensile strength.

Table 5.4.1 Mechanical properties for acceptance purposes: carbon-manganese steel forgings for crankshafts

Tensile strength N/mm^2	Yield stress N/mm^2 minimum	Elongation on 5,65 $\sqrt{S_0}$ % minimum		Hardness Brinell
		Long.	Tang.	
400 – 520	200	26	19	110 – 150
440 – 560	220	24	18	125 – 160
480 – 600	240	22	16	135 – 175
520 – 640	260	21	15	150 – 185
560 – 680	280	20	14	160 – 200
600 – 750	300	18	13	175 – 215
640 – 790	320	17	12	185 – 230
680 – 830	340	16	12	200 – 240
720 – 870	350	15	11	210 – 250
760 – 910	380	14	18	225 – 265
Intermediate values may be obtained by interpolation.				

4.5.7 Forgings may be supplied to any specified minimum tensile strength selected within the general limits detailed in *Table 5.4.1 Mechanical properties for acceptance purposes: carbon-manganese steel forgings for crankshafts* to *Table 5.4.3 Mechanical properties for acceptance purposes: alloy steel forgings for crankshafts - Quenched and tempered*.

4.5.8 The results of all tensile tests are to comply with the requirements of *Table 5.4.1 Mechanical properties for acceptance purposes: carbon-manganese steel forgings for crankshafts*, *Table 5.4.2 Mechanical properties for acceptance purposes: alloy steel forgings for crankshafts - Normalised and tempered* or *Table 5.4.3 Mechanical properties for acceptance purposes: alloy steel forgings for crankshafts - Quenched and tempered* appropriate to the specified minimum tensile strength.

4.5.9 Where more than one tensile test is taken from a forging, the variation in tensile strength is not to exceed the following:

Specified minimum tensile strength N/mm^2	Difference in tensile strength N/mm^2
<600	70
≥600 <900	100
≥900	120

4.5.10 For small crankshaft forgings which have been batch tested, the hardness values are to be not less than those given in *Table 5.4.1 Mechanical properties for acceptance purposes: carbon-manganese steel forgings for crankshafts* to *Table 5.4.3 Mechanical properties for acceptance purposes: alloy steel forgings for crankshafts - Quenched and tempered*, as appropriate. The variation in hardness in each batch is to comply with the following:

Specified minimum tensile strength (N/mm^2)	Difference in hardness (Brinell number)
<600	not more than 25
≥600 <900	not more than 35
≥900	not more than 42

Table 5.4.2 Mechanical properties for acceptance purposes: alloy steel forgings for crankshafts - Normalised and tempered

Tensile strength N/mm^2	Yield stress N/mm^2 minimum	Elongation on 5,65 $\sqrt{S_o}$ % minimum		Hardness Brinell
		Long.	Tang.	
600 – 750	330	18	14	175 – 215
650 – 800	355	17	13	190 – 235
700 – 850	380	16	12	205 – 245
750 – 900	405	15	11	215 – 260
800 – 950	430	14	10	235 – 275
Intermediate values may be obtained by interpolation.				

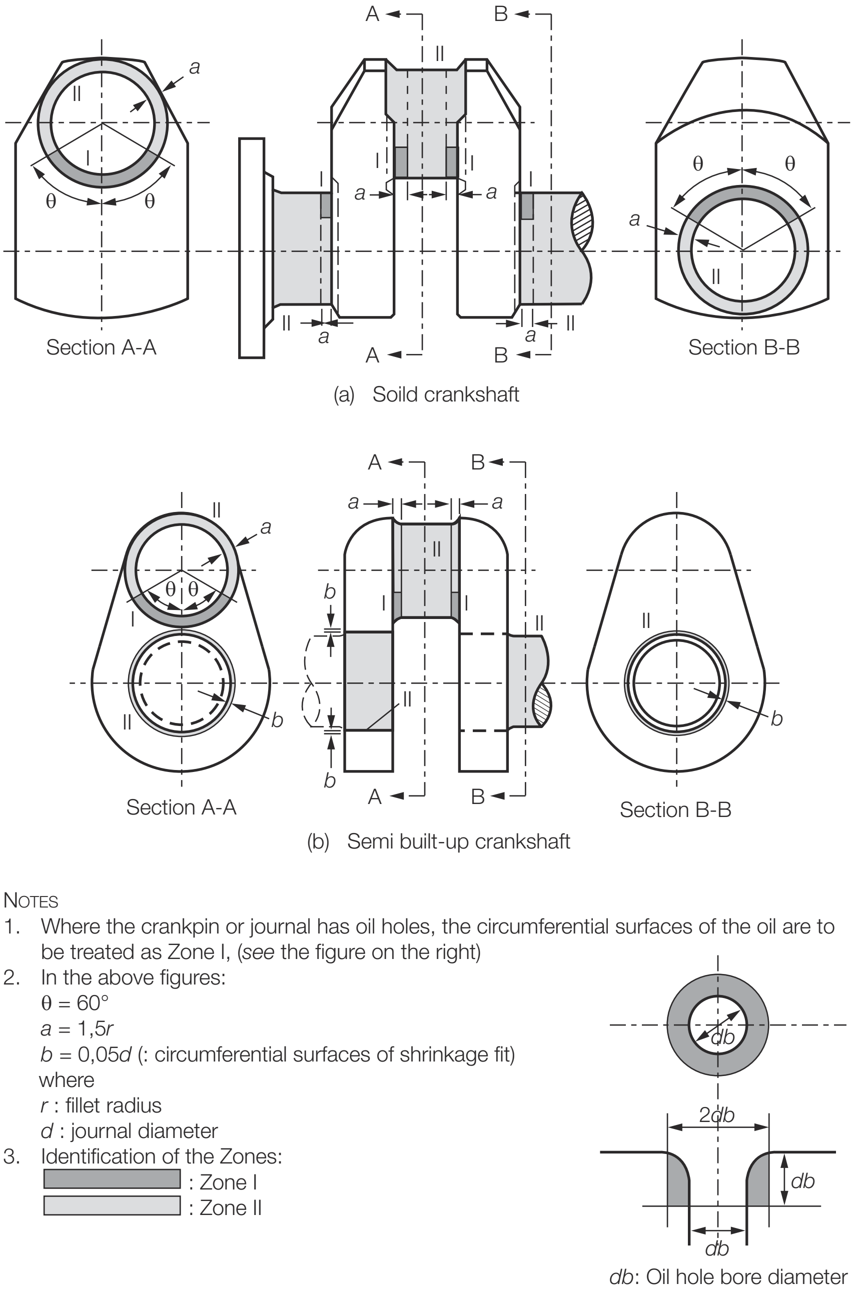
Table 5.4.3 Mechanical properties for acceptance purposes: alloy steel forgings for crankshafts - Quenched and tempered

Tensile strength N/mm^2	Yield stress N/mm^2 minimum	Elongation on 5,65 $\sqrt{S_o}$ % minimum		Hardness Brinell
		Long.	Tang.	
600-750	420	18	14	175-215
650-800	450	17	13	190-235

700-850	480	16	12	205-245
750-900	530	15	11	215-260
800-950	590	14	10	235-275
850-1000	640	13	9	245-290
900-1150	690	13	9	260-320
950-1150	750	12	8	275-340
1000-1200	810	12	8	290-365
Intermediate values may be obtained by interpolation.				

4.6 Non-destructive examination

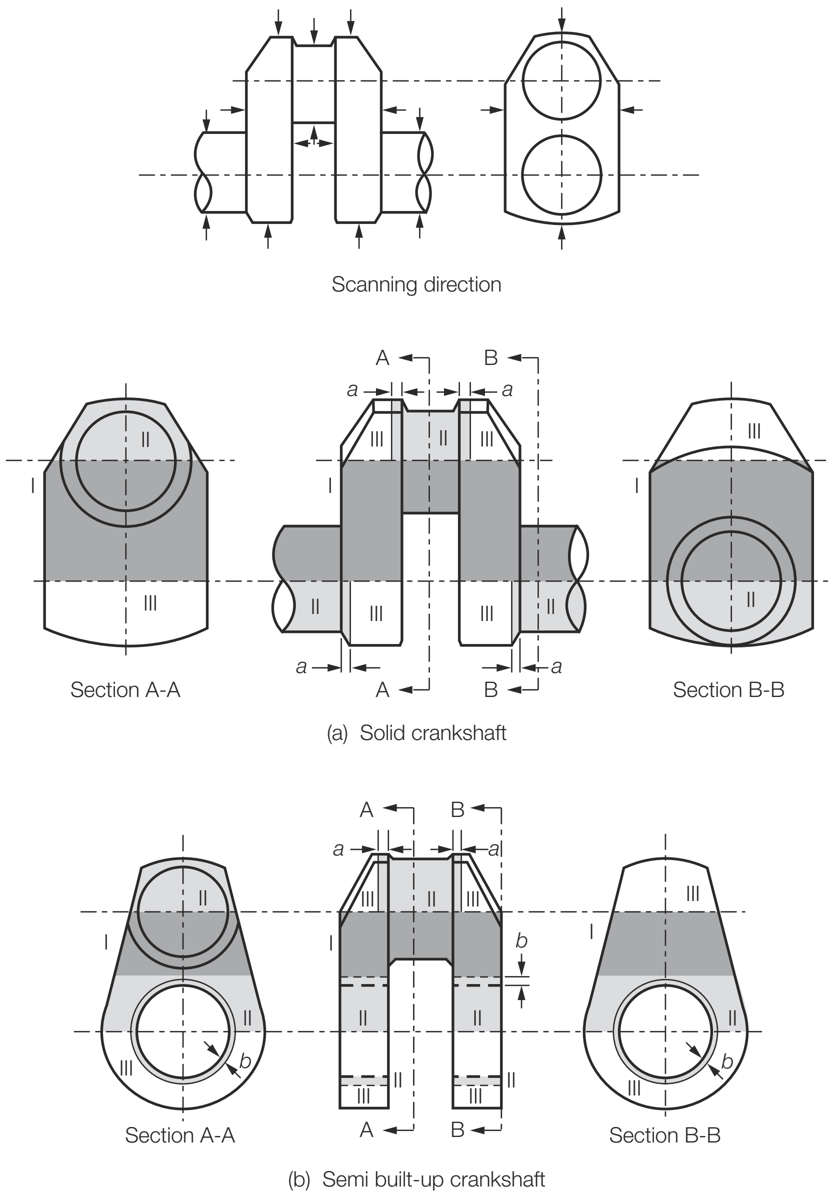
4.6.1 Magnetic particle or dye penetrant testing as detailed in *Ch 5, 1.8 Visual and non-destructive examination 1.8.5* and *Ch 5, 2.5 Non-destructive examination* is to be carried out on all forgings for crankshafts. Where applicable, this is to include all surfaces which have been flame-cut, but not subsequently machined during manufacture. Particular attention is to be given to the testing of the pins, journals and associated fillet radii of solid forged crankshafts and to the pins and fillet radii of combined web and pin forgings. The extent of testing is shown in *Figure 5.4.3 Zones for magnetic particle/dye penetrant testing on crankshafts*.



NOTES
1. Where the crankpin or journal has oil holes, the circumferential surfaces of the oil are to be treated as Zone I, (*see* the figure on the right)
2. In the above figures:
   θ = 60°
   a = 1,5*r*
   b = 0,05*d* (: circumferential surfaces of shrinkage fit)
   where
   r : fillet radius
   d : journal diameter
3. Identification of the Zones:
   : Zone I
   : Zone II

Figure 5.4.3 Zones for magnetic particle/dye penetrant testing on crankshafts

4.6.2 The manufacturer is to carry out an ultrasonic examination of all forgings as detailed in *Ch 5, 1.8 Visual and non-destructive examination 1.8.8* and *Ch 5, 2.5 Non-destructive examination*. The extent of ultrasonic testing is shown in *Figure 5.4.4 Zones for ultrasonic testing on crankshafts*.



Notes

1. In the above figures:
   a = 0,1*d* or 25 mm, whichever is greater
   b = 0,05*d* or 25 mm, whichever is greater (: circumstances of shrinkage fit)
   where
   d : pin or journal diameter
2. The mid third area of crank pins and/or journals within a raduis of 0,25*d* between the webs may generally be coordinated to Zone II
3. Identification of the Zones:
   : Zone I
   : Zone II
   : Zone III

Figure 5.4.4 Zones for ultrasonic testing on crankshafts

4.6.3 Surface inspection acceptance criteria are to be in accordance with *Ch 5, 2.5 Non-destructive examination* and with *Table 5.4.4 Surface inspection acceptance for crankshaft forgings – Allowable number and size of indications in a reference area of*

225 cm^2 . Other acceptance criteria may be applied, providing they meet these minimum criteria, and is to the satisfaction of the Surveyor.

Table 5.4.4 Surface inspection acceptance for crankshaft forgings – Allowable number and size of indications in a reference area of 225 cm^2

Inspection zone	Maximum number of indication	Type of indication	Maximum number each type	Maximum dimension of single indication, mm
I Critical fillet area	0	Linear Non-linear Aligned	0 0 0	- - -
II Important fillet area	3	Linear Non-linear Aligned	0 3 0	- 3,0 -
III Journal surfaces	3	Linear Non-linear Aligned	0 3 0	- 5,0 -

4.6.4 Ultrasonic acceptance criteria are shown in *Table 5.4.5 Ultrasonic acceptance criteria for crankshafts*. Other acceptance criteria may be applied, providing they meet these minimum criteria, and is to the satisfaction of the Surveyor.

Table 5.4.5 Ultrasonic acceptance criteria for crankshafts

Type of forging	Zone	Allowable disc shape according to Distance Gain Size (DGS), mm	Allowable length of indication, mm *see* Note
Crank shaft	I II III	$d \leq 2,0$ $d \leq 3,0$ $d \leq 4,0$	– ≤10 ≤15
Note For accumulations of two or more isolated indications which are subjected to registration, the minimum distance between two neighbouring indications is to be at least the length of the larger indication. This applies to the distance in axial direction as to the distance in depth. Isolated indications with less distance are to be determined as one single indication.			

■ *Section 5*
Forgings for gearing

5.1 Scope

5.1.1 Provision is made in this Section for carbon-manganese and alloy steel forgings intended for use in the construction of gearing for main propulsion and for driving electric generators.

5.1.2 Gear wheel and rim forgings with a specified minimum tensile strength not exceeding 760 N/mm^2 (760–910 N/mm^2 acceptance range) may be made in carbon-manganese steel. Gear wheel or rim forgings where the specified minimum tensile strength is in excess of 760 N/mm^2, and all pinion or pinion sleeve forgings, are to be made in a suitable alloy steel. Specifications for alloy steel components and for quill shafts, giving chemical composition, heat treatment and mechanical properties, are to be submitted for approval.

5.1.3 Forgings for flexible couplings, quill shafts and gear wheel shafts are to comply with the requirements of *Ch 5, 3 Forgings for shafting and machinery*.

5.1.4 Manufacturers' test certificates for forgings may be accepted where the transmitted power does not exceed 220 kW (300 shp) for main propulsion and 100 kW (150 shp) for auxiliary drives.

5.2 Manufacture

5.2.1 All forgings are to be made with sufficient material to allow an adequate machining allowance on all surfaces for the removal of unsound or decarburised material.

5.2.2 The hardenabilty of the forged material is to be checked at random intervals using an end quench test complying with a National or International Standard.

5.2.3 The grain size is to be checked on a random basis in accordance with the testing and reporting procedures of ASTM E 112, or an equivalent National Standard, and is to be within the range 5 to 8.

5.2.4 The microstructure of the hardened case is to be mainly martensite, with a maximum content of 15 per cent of retained austenite.

5.3 Chemical composition

5.3.1 The chemical composition of ladle samples is to comply with *Ch 5, 3.2 Chemical composition 3.2.1* for carbon and carbon-manganese steels and *Ch 5, 1.4 Chemical composition 1.4.3* for alloy steels.

5.4 Heat treatment

5.4.1 Except as provided in *Ch 5, 5.4 Heat treatment 5.4.4* and *Ch 5, 5.4 Heat treatment 5.4.5*, forgings may be either normalised and tempered or quenched and tempered in accordance with the approved specification. The tempering temperature is to be not less than 550°C.

5.4.2 Where forgings are machined prior to heat treatment, the allowance left for final machining is to be sufficient to remove the decarburised surface material, taking into account any bending or distortion which may occur.

5.4.3 When the teeth of a pinion or gear wheel are to be surface hardened, i.e. carburised, nitrided or induction hardened, the proposed specification together with details of the process and practice are to be submitted for approval. For purposes of initial approval, the gear manufacturer is required to demonstrate by test that the surface hardening of the teeth is uniform and of the required depth and that it does not impair the soundness and quality of the steel.

5.4.4 Where induction hardening of nitriding is to be carried out after machining of the gear teeth, the forgings are to be heat treated at an appropriate stage to a condition suitable for this subsequent surface hardening.

5.4.5 Forgings for gears which are to be carburised after final machining are to be supplied in either the fully annealed or the normalised and tempered condition, suitable for subsequent machining and carburising.

5.5 Mechanical tests for through hardened, induction hardened or nitrided forgings

5.5.1 At least one tensile test specimen is to be taken from each forging in carbon or carbon-manganese steel, and at least one tensile specimen from forgings in alloy steel. Sufficient test material is to be provided for this purpose and the test specimens are to be taken as follows:

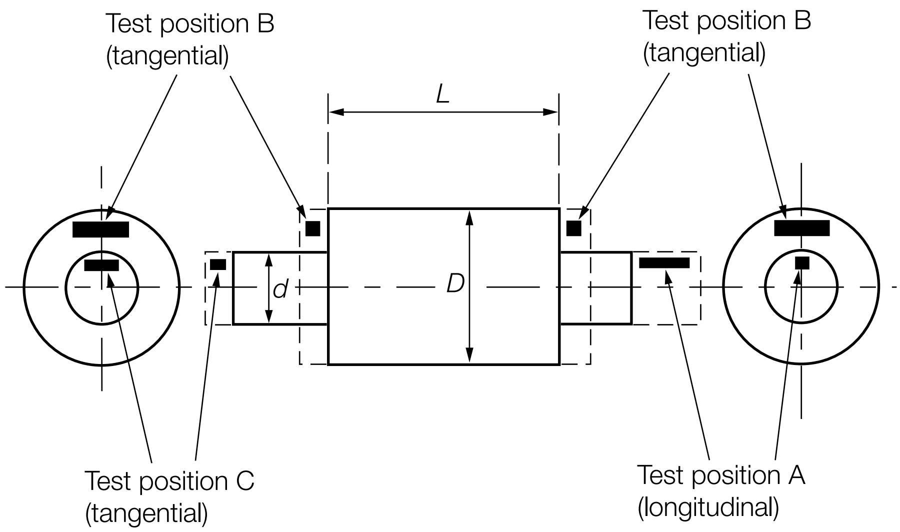
(a) For pinion forgings where the finished diameter of the toothed portion exceeds 200 mm, tests are to be taken in a tangential direction and adjacent to the toothed portion (test position B in *Figure 5.5.1 Test positions for forgings for gearing*). Where the dimensions preclude the preparation of tests from this position, tests in a tangential direction are to be taken from the end of the journal (test position C in *Figure 5.5.1 Test positions for forgings for gearing*). If, however, the journal diameter is 200 mm or less, tests are to be taken in a longitudinal direction (test position A in *Figure 5.5.1 Test positions for forgings for gearing*). Where the finished length of the toothed portion exceeds 1250 mm, tests are to be taken from each end.

(b) For small pinion forgings where the finished diameter of the toothed portion is 200 mm or less, tests are to be taken in a longitudinal direction (test position A in *Figure 5.5.1 Test positions for forgings for gearing*).

(c) For gear wheel forgings, tests are to be taken in a tangential direction (from one of the test positions B in *Figure 5.5.2 Test position B*).

(d) For gear wheel rim forgings, tests are to be taken in a tangential direction (from one of the test positions A in *Figure 5.5.3 Test position A*). Where the finished diameter exceeds 2500 mm or the mass (as heat treated but excluding test material) exceeds 3 tonnes, tests are to be taken from two diametrically opposite positions (test positions A in *Figure 5.5.3 Test position A*).

(e) For pinion sleeve forgings, tests are to be taken in a tangential direction (from one of the test positions C in *Figure 5.5.4 Test position C*). Where the finished length exceeds 1250 mm, tests are to be taken from each end.



L = length of toothed portion, in metres
D = diameter of toothed portion, in metres
d = journal diameter, in metres

Figure 5.5.1 Test positions for forgings for gearing

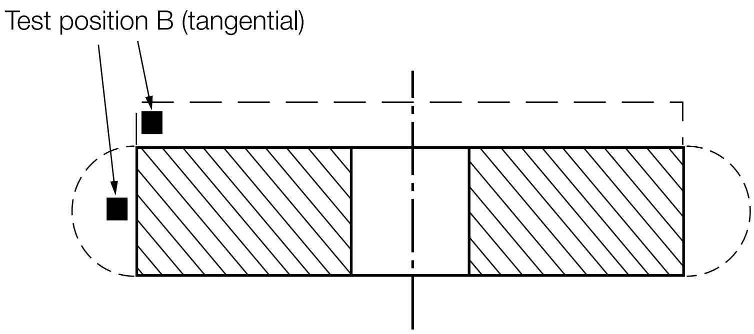


Figure 5.5.2 Test position B

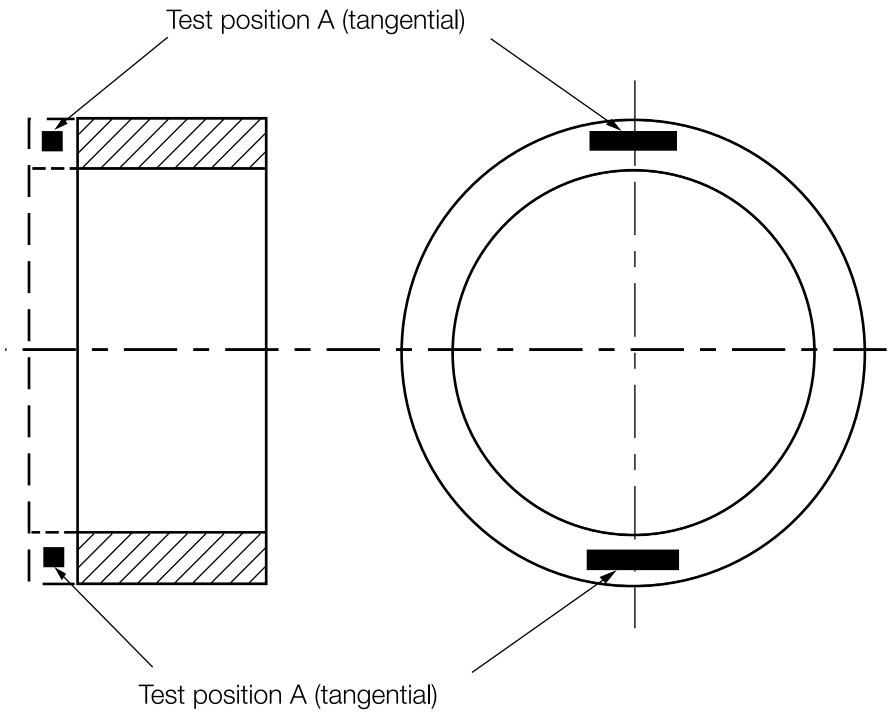


Figure 5.5.3 Test position A

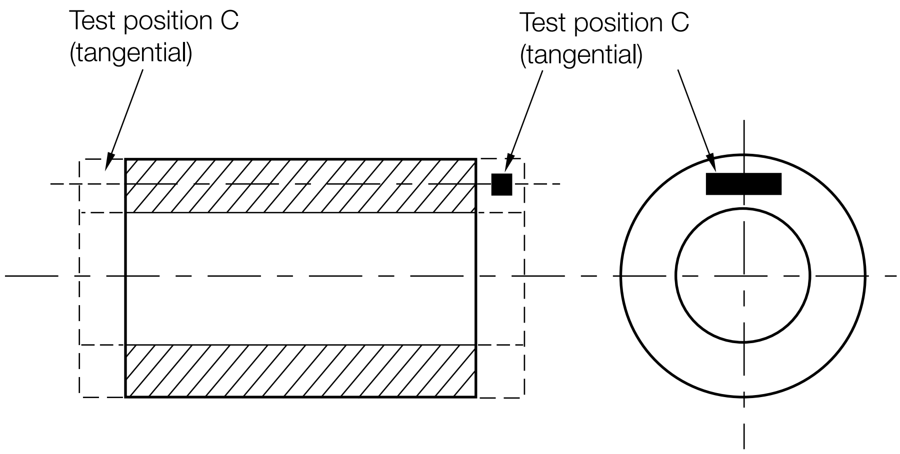


Figure 5.5.4 Test position C

5.5.2 As an alternative to *Ch 5, 5.5 Mechanical tests for through hardened, induction hardened or nitrided forgings 5.5.1*, small forgings may be batch tested in accordance with *Ch 5, 1.6 Test material 1.6.4* provided that, in addition, hardness tests are carried out on each forging.

5.5.3 *Table 5.5.1 Mechanical properties for acceptance purposes: carbon-manganese steels for gear wheel and rim forgings* to *Table 5.5.3 Mechanical properties for acceptance purposes: alloy steel gear forgings - Quenched and tempered*give the minimum requirements for yield stress and elongation corresponding to different strength levels, but it is not intended that these should necessarily be regarded as specific grades. The strength levels have been given in multiples of 40 N/mm^2, or 50 N/mm^2 in the case of alloy steels, to facilitate interpolation for intermediate values of specified minimum tensile strength.

Table 5.5.1 Mechanical properties for acceptance purposes: carbon-manganese steels for gear wheel and rim forgings

Tensile strength N/mm^2 (*see* Note)	Yield stress N/mm^2 minimum	Elongation on 5,65 $\sqrt{S_0}$ % minimum		Hardness Brinell
		Rims	Wheels	
400 - 520	200	26	22	110 - 150
440 - 560	220	24	21	125 - 160
480 - 600	240	22	19	135 - 175
520 - 640	260	21	18	150 - 185
560 - 680	280	20	17	160 - 200
600 - 750	300	18	15	175 - 215
640 - 790	320	17	14	185 - 230
680 - 830	340	16	14	200 - 240
720 - 870	360	15	13	210 - 250
760 - 910	380	14	12	225 - 265
Intermediate values may be obtained by interpolation.				
Note When the specified minimum tensile strength exceeds 700 N/mm^2 forgings are to be supplied only in the quenched and tempered condition.				

5.5.4 Forgings may be supplied to any specified minimum tensile strength selected within the general limits detailed in *Table 5.5.1 Mechanical properties for acceptance purposes: carbon-manganese steels for gear wheel and rim forgings* to *Table 5.5.3 Mechanical properties for acceptance purposes: alloy steel gear forgings - Quenched and tempered*.

5.5.5 The results of all tensile tests are to comply with the requirements of *Table 5.5.1 Mechanical properties for acceptance purposes: carbon-manganese steels for gear wheel and rim forgings*, *Table 5.5.2 Mechanical properties for acceptance purposes: alloy steel gear wheel and rim forgings - Normalised and tempered* or *Table 5.5.3 Mechanical properties for acceptance purposes: alloy steel gear forgings - Quenched and tempered*, appropriate to the specified minimum tensile strength. Unless otherwise agreed, the specified minimum tensile strength is to be not less than 800 N/mm^2 (800–950 N/mm^2 acceptance range) for induction hardened or nitrided gear forgings.

5.5.6 Where more than one tensile test is taken from a forging, the variation in tensile strength is not to exceed the following:

Specified minimum tensile strength N/mm^2	Difference in tensile strength N/mm^2
<600	70
≥600 <900	100
≥900	120

5.5.7 Hardness tests are to be carried out on all forgings after completion of heat treatment and prior to machining the gear teeth. The hardness is to be determined at four positions equally spaced around the circumference of the surface where teeth will subsequently be cut. Where the finished diameter of the toothed portion exceeds 2500 mm, the number of test positions is to be increased to eight. Where the width of a gear wheel rim forging exceeds 1250 mm, the hardness is to be determined at eight positions at each end of the forging.

Table 5.5.2 Mechanical properties for acceptance purposes: alloy steel gear wheel and rim forgings - Normalised and tempered

Tensile strength N/mm^2	Yield stress N/mm^2 minimum	Elongation on 5,65 $\sqrt{S_o}$ % minimum		Hardness Brinell
		Rims	Wheels	
600 – 750	330	18	16	175 – 215
650 – 800	355	17	15	190 – 235
700 – 850	380	16	14	205 – 245
750 – 900	405	15	13	215 – 260
800 – 950	430	14	12	235 – 275
850 – 1000	455	13	11	245 – 290
Intermediate values may be obtained by interpolation.				

Table 5.5.3 Mechanical properties for acceptance purposes: alloy steel gear forgings - Quenched and tempered

Tensile strength N/mm^2 (*see* Notes 1 and 2)	Yield stress N/mm^2 minimum (*see* Note 2)	Elongation on 5,65 $\sqrt{S_o}$ % minimum			Hardness Brinell
		A	B	C	
600 – 750	420	18	16	14	175 – 215
650 – 800	450	17	15	13	190 – 235
700 – 850	480	16	14	12	205 – 245
750 – 900	530	15	13	11	215 – 260
800 – 950	590	14	12	10	235 – 275
850 – 1000	640	13	11	9	245 – 290
900 – 1050	690	13	11	9	260 – 310
950 – 1100	750	12	10	8	275 – 330
1000 – 1150	810	12	10	8	290 – 340
1050 – 1200	870	11	9	7	310 – 365
= Column A is applicable to tests from gear rims and to longitudinal tests from pinions. = Column B is applicable to tests from gear wheels and to tangential tests from pinions. = Column C is applicable to tests from pinion sleeves.					
Intermediate values may be obtained by interpolation					
Note 1. For gear wheel and rim forgings the specified minimum tensile strength is not to exceed 850 N/mm^2. Note 2. For carburised gear forgings the requirements for minimum yield stress and maximum tensile strength are not applicable.					

5.5.8 For small gear forgings which are batch tested, at least one hardness test is to be carried out on each forging.

5.5.9 The results of all hardness tests are to comply with the appropriate requirements of*Table 5.5.1 Mechanical properties for acceptance purposes: carbon-manganese steels for gear wheel and rim forgings* to *Table 5.5.3 Mechanical properties for acceptance purposes: alloy steel gear forgings - Quenched and tempered*. The difference between the highest and lowest values on any one forging is not to exceed the following:

Specified minimum tensile strength (N/mm$^{2)}$	Difference in hardness (Brinell number)
<600	25
≥600 <900	35
≥900	42

5.5.10 On nitrided or induction hardened components, hardness tests are also to be made on the teeth when surface hardening and grinding have been completed. The results are to comply with the approved specification.

5.6 Mechanical tests for carburised forgings

5.6.1 Sufficient test material is to be provided for preliminary tests at the forge and for final tests after completion of carburising. For this purpose, duplicate sets of test material are to be taken from positions as detailed in *Ch 5, 5.5 Mechanical tests for through hardened, induction hardened or nitrided forgings 5.5.1*, except that, irrespective of the dimensions or mass of the forging, tests are required from one position only, and in the case of forgings with integral journals are to be cut in a longitudinal direction. The test material which is to be used for measurements of case depth, hardness, grain size and residual austenite as well as mechanical properties is to be machined to a coupon of diameter of $\frac{D}{4}$ or 30 mm, whichever is less, where D is the finished diameter of the toothed portion.

5.6.2 For small forgings, where a system of batch testing is adopted, the test material may be prepared from surplus steel from the same cast provided that the forging reduction approximates to that of the actual gear forgings. The test samples are to be correctly identified and heat treated with the forgings they represent.

5.6.3 For preliminary tests at the forge, one set of test material is to be given a blank carburising and heat treatment cycle simulating that which will be subsequently applied to the forgings.

5.6.4 For final acceptance tests, the second set of test material is to be blank carburised and heat treated together with the forgings which it represents.

5.6.5 At the discretion of the forgemaster or gear manufacturer, test samples of larger cross-section than in *Ch 5, 5.6 Mechanical tests for carburised forgings 5.6.1* may be either carburised or blank carburised, but these are to be machined to the required diameter prior to the final quenching and stress relieving heat treatment.

5.6.6 At least one tensile specimen is to be prepared from each sample of test material.

5.6.7 Unless otherwise agreed, the specified minimum tensile strength is to be not less than 750 N/mm^2, and the results of all tensile tests are to comply with the requirements given in *Table 5.5.3 Mechanical properties for acceptance purposes: alloy steel gear forgings - Quenched and tempered*.

5.6.8 Where it is proposed to adopt alternatives to the requirements of *Ch 5, 5.6 Mechanical tests for carburised forgings 5.6.1* to *Ch 5, 5.6 Mechanical tests for carburised forgings 5.6.7*, full details are to be submitted to the Surveyor for consideration.

5.7 Non-destructive examination

5.7.1 Magnetic particle or liquid penetrant testing is to be carried out on the teeth of all surface hardened forgings. This examination may also be requested on the finished machined teeth of through hardened gear forgings.

5.7.2 The manufacturer is to carry out an ultrasonic examination of all forgings where the finished diameter of the surfaces, where teeth will be cut, is in excess of 200 mm, and is to provide the Surveyor with a signed statement that such inspection has not revealed any significant internal defects.

5.7.3 On gear forgings where the teeth have been surface hardened, additional test pieces may be required to be processed with the forgings and subsequently sectioned to determine the depth of the hardened zone. These tests are to be carried out at the discretion of the Surveyor, and for induction or carburised gearing the depth of the hardened zone is to be in accordance with the approved specification. For nitrided gearing, the full depth of the hardened zone, (i.e. depth to core hardness), is to be not less than 0,5 mm and the hardness at a depth of 0,25 mm is to be not less than 500 HV.

■ *Section 6*
Forgings for turbines

6.1 Scope

6.1.1 Provision is made in this Section for ferritic steel forgings for turbine rotors, discs and spindles, turbine-driven generator rotors and compressor rotors.

6.1.2 Plans for rotor forgings are to state whether the rotor is intended for propulsion or auxiliary machinery and the shaft power of auxiliary turbines. In the case of a rotor which is to be tested for thermal stability, the maximum operating temperature and the proposed test temperature are also to be stated.

6.1.3 Specifications of alloy steel forgings giving the proposed chemical composition, heat treatment and mechanical properties are to be submitted for approval with the plans of the components.

6.1.4 Where it is proposed to use rotors of welded construction, the compositions of the steels for the forgings are to be submitted for special consideration, together with details of the proposed welding procedure. Welding procedure tests may be required.

6.2 Manufacture

6.2.1 Forgings are to be manufactured in accordance with the requirements of *Ch 5, 1 General requirements*, except that for rotors the forging reduction is to be not less than 2,5 to 1. Where an upsetting operation is included in the manufacturing procedure, the above requirement applies to the cross-sectional area of the upset bloom and not to that of the ingot.

6.3 Chemical composition

6.3.1 The chemical composition of ladle samples is to comply with *Ch 5, 3.2 Chemical composition 3.2.1* for carbon and carbon-manganese steels and *Ch 5, 1.4 Chemical composition 1.4.3* for alloy steels.

6.4 Heat treatment

6.4.1 Forgings are to be supplied in the heat treated condition, and the thermal treatment at all stages is to be such as to avoid the formation of hair-line cracks. At a suitable stage of manufacture, the forgings are to be reheated above the upper critical point to refine the grain, cooled in an approved manner and then tempered to produce the desired mechanical properties.

6.4.2 Where forgings receive their main heat treatment before machining, they are to be stress relieved after rough machining. Forgings which are heat treated in the rough machined condition need not be stress relieved provided that they have been slowly cooled from the tempering temperature.

6.4.3 The tempering and stress relieving temperatures are to be not less than 550°C for carbon and carbon-manganese steels, and not less than 600°C for alloy steels. The holding times and subsequent cooling rates are to be such that the forging in its final condition is free from harmful residual stresses.

6.4.4 Details of the proposed heat treatment for rotors of welded construction are to be submitted for approval.

6.5 Mechanical tests

6.5.1 At least one tensile test specimen, cut in a longitudinal direction, is to be taken from each rotor forging. For forgings exceeding both 3 tonnes in mass and 2000 mm in length, tests are to be taken from each end.

6.5.2 For rotor forgings of all main propulsion machinery and of auxiliary turbines exceeding 1100 kW, tangential and, where the dimensions permit, radial tensile tests are to be taken from the end of the body corresponding to the top end of the ingot, *see Figure 5.6.1 Test positions for turbine rotor forgings*.

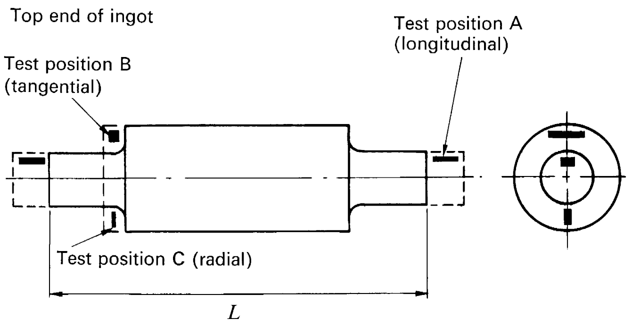


Figure 5.6.1 Test positions for turbine rotor forgings

6.5.3 For each turbine disc, at least one tensile test specimen is to be cut in a tangential direction from material at the hub, *see Figure 5.6.2 Test positions for turbine disc forgings*.

6.5.4 For the tests required by *Ch 5, 6.5 Mechanical tests 6.5.1*, sufficient test material is to be left on each forging and is not to be removed until all heat treatment, including stress relieving, has been completed. In this connection, a thermal stability test does not form part of the heat treatment of a turbine forging. Any excess test material is not to be completely severed from a forging until all the mechanical tests have been completed with satisfactory results.

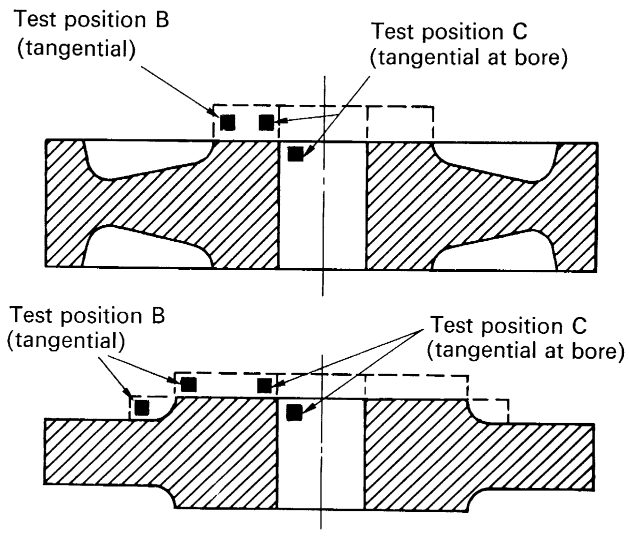


Figure 5.6.2 Test positions for turbine disc forgings

6.5.5 *Table 5.6.1 Mechanical properties for acceptance purposes: carbon-manganese steel forgings for turbines - Normalised and tempered* and *Table 5.6.2 Mechanical properties for acceptance purposes: alloy steel forgings for turbines - Quenched and tempered or normalised and tempered* give the minimum requirements for yield stress, elongation and reduction of area corresponding to different strength levels, but it is not intended that these should necessarily be regarded as specific grades. The strength levels have been given in multiples of 40 N/mm^2, or 50 N/mm^2 for alloy steels, to facilitate interpolation for intermediate values of specified minimum tensile strength.

6.5.6 Forgings may be supplied to any specified minimum tensile strength selected within the general limits detailed in *Table 5.6.1 Mechanical properties for acceptance purposes: carbon-manganese steel forgings for turbines - Normalised and tempered* or *Table 5.6.2 Mechanical properties for acceptance purposes: alloy steel forgings for turbines - Quenched and tempered or normalised and tempered*.

6.5.7 The results of all tensile tests are to comply with the requirements of *Table 5.6.1 Mechanical properties for acceptance purposes: carbon-manganese steel forgings for turbines - Normalised and tempered* or *Table 5.6.2 Mechanical properties for acceptance purposes: alloy steel forgings for turbines - Quenched and tempered or normalised and tempered* appropriate to the specified minimum tensile strength. For monobloc rotor forgings, the specified minimum tensile strength is not to exceed 800 N/mm^2.

6.6 Non-destructive examination

6.6.1 The end faces of the body of rotor forgings and the end faces of the boss and the bore surface of each turbine disc are to be machined to a fine smooth finish for visual and magnetic particle examination.

6.6.2 The manufacturer is to carry out an ultrasonic examination of each forging and is to provide the Surveyor with a signed statement that such inspection has not revealed any significant internal defects.

6.6.3 Rotor forgings for propulsion machinery and for auxiliary turbines exceeding 1100 kW are to be hollow bored for internal examination. The surface of the bore is to have a fine smooth finish and is to be examined by means of an optical instrument of suitable magnification. Where the bore size permits, magnetic particle examination is also to be carried out. These examinations are to be confirmed by the Surveyor. Alternatively, an approved method of ultrasonic examination may be accepted instead of hollow boring. Details of the proposed method of ultrasonic examination are to be submitted for special consideration.

Table 5.6.1 Mechanical properties for acceptance purposes: carbon-manganese steel forgings for turbines - Normalised and tempered

Tensile strength N/mm^2	Yield stress N/mm^2 minimum	Elongation 5,65 $\sqrt{S_0}$ % minimum			Reduction of area % minimum		
		A	B	C	A	B	C
400 – 520	200	26	22	18	50	40	35
440 – 560	220	24	21	17	50	40	35
480 – 600	240	22	19	15	45	35	30
520 – 640	260	21	18	14	45	35	30
560 – 680	280	20	17	13	40	30	25
600 – 720	300	18	15	12	40	30	25

Columns A are applicable to longitudinal tests from rotor and spindle forgings.
Columns B are applicable to tangential tests from rotor forgings.
Columns C are applicable to radial tests from rotor forgings.
Intermediate values may be obtained by interpolation.

6.7 Thermal stability tests

6.7.1 Thermal stability tests after heat treatment and rough machining of the turbine rotors, referred to in the relevant Rules dealing with design and construction, are to be undertaken in properly constructed furnaces, using accurate and reliable measuring equipment. Each test is to be carried out in accordance with the following recommended procedure:

(a) Five bands are to be machined concentric with the axis of rotation. Two of these are to be reference bands and are to be positioned at or near the locations of the bearings. The remaining three bands are to be test bands located one as near as possible to the mid-length, and the other two near each end of the body. Where the length of a rotor is such that five bands cannot be provided, alternative proposals are to be submitted to the Surveyor for his approval.
(b) Four positions, 90° apart, are to be stamped A, B, C and D on the coupling end of the rotor.
(c) The whole of the body, and as much of the shaft at either end as will include the positions of the glands, is to be enclosed in the furnace. In the case of a rotor having an overhung astern wheel, the astern wheel is also to be enclosed in the furnace during the first test.
(d) The rotor is to be rotated at a uniform and very low speed.
(e) The deflections at all bands are to be recorded at the A, B, C and D positions. Initial cold readings are to be taken prior to heating.
(f) The rotor is to be heated uniformly and slowly. Temperatures are to be recorded continuously at the surface of the rotor and, if practicable, in the bore at the mid-length of the body. In no circumstances is the surface temperature to exceed the

temperature at which the rotor was tempered. During heating, the rate of rise of temperature is to be such as to avoid excessive temperature gradients in the rotor.

(g) The maximum or holding temperature is to be not less than 28°C above the maximum operating temperature of the rotor. For the purposes of the test, the holding period is to start when the rotor has attained a uniform and specified temperature. The rotor is to be held under the specified temperature conditions until not less than three consecutive hourly readings of deflections show the radial eccentricity to be constant within 0,006 mm on all test bands.

(h) The turbine rotor is to be rotated during cooling until the temperature is not more than 100°C. The rate of cooling is to be such as to avoid excessive temperature gradients in the rotor.

(i) Final cold readings are to be taken.

Table 5.6.2 Mechanical properties for acceptance purposes: alloy steel forgings for turbines - Quenched and tempered or normalised and tempered

Tensile strength N/mm^2 (*see* Note)	Yield stress N/mm^2 minimum Normalised and tempered	Yield stress N/mm^2 minimum Quenched and tempered	Elongation on 5,65 $\sqrt{S_o}$ % minimum			Reduction of area % minimum		
			A	B	C	A	B	C
500 – 650	275	–	22	20	18	50	40	35
550 – 700	300	–	20	18	16	50	40	35
600 – 750	330	410	18	16	14	50	40	35
650 – 800	355	450	17	15	13	50	40	35
700 – 850	385	490	16	14	12	45	35	30
750 – 900	–	530	15	13	11	45	35	30
800 – 950	–	590	14	12	10	45	35	30
850 – 1000	–	640	13	11	9	40	30	25
900 – 1050	–	690	13	11	9	40	30	25
950 – 1100	–	750	12	10	8	40	30	25
1000 – 1150	–	810	12	10	8	40	30	25

Columns A are applicable to longitudinal tests from rotor and spindle forgings.
Columns B are applicable to tangential tests from rotor and spindle forgings, and to tangential tests from discs – test position B in *Figure 5.6.2 Test positions for turbine disc forgings*.
Columns C are applicable to radial test from rotor forgings and to tangential tests from discs – test position C in *Figure 5.6.2 Test positions for turbine disc forgings*.
Intermediate values may be obtained by interpolation.

6.7.2 The movements of the axis of the rotor in relation to the reference bands are to be determined from polar plots of the deflection readings. The radial movement of the shaft axis, as determined by the difference between the final hot and the final cold movements, is not to exceed 0,025 mm on any one band. As verification that test equipment and conditions are satisfactory, it is required that similar determinations of differences between initial cold and final cold movements do not exceed 0,025 mm on any one band.

6.7.3 If the results of the test on a rotor fail to meet either or both of the requirements in *Ch 5, 6.7 Thermal stability tests 6.7.2*, the test may be repeated if requested by the maker and agreed by the Surveyor. In the case of a rotor failing to meet the requirements of a thermal stability test, the rotor is deemed unacceptable. Proposals for the rectification of thermal instability of a rough machined rotor are to be submitted for special consideration.

Section 7
Forgings for boilers, pressure vessels and piping systems

7.1 Scope

7.1.1 Provision is made in this Section for carbon-manganese and low alloy steel forgings intended for use in the construction of boilers, pressure vessels and piping systems where the design temperature is not lower than 0°C.

7.1.2 In addition to specifying mechanical properties at ambient temperature for the purposes of acceptance testing, these requirements give details of appropriate mechanical properties at elevated temperatures to be used for design purposes.

7.1.3 Forgings used in the construction of equipment for the containment of liquefied gases are to comply with the requirements of *Ch 5, 8 Ferritic steel forgings for low temperature service*, except for those used in piping systems, where the design temperature is not lower than 0°C. Forgings for other pressure vessels and piping systems, where the use of steels with guaranteed impact properties at low temperatures is required, are also to comply with *Ch 5, 8 Ferritic steel forgings for low temperature service*.

7.2 Chemical composition

7.2.1 The chemical composition of ladle samples is to comply with the appropriate requirements of *Table 5.7.1 Chemical composition*.

7.3 Heat treatment

7.3.1 Carbon-manganese steel forgings are to be normalised, normalised and tempered or quenched and tempered.

7.3.2 Alloy steel forgings are to be normalised and tempered or quenched and tempered.

7.3.3 No forging is to be fully heat treated more than twice.

7.4 Mechanical tests

7.4.1 Except as provided in *Ch 5, 7.4 Mechanical tests 7.4.2* and *Ch 5, 7.4 Mechanical tests 7.4.4*, at least one tensile test is to be taken from each forging and, where the dimensions and shape allow, the test specimen is to be cut in the longitudinal direction.

Table 5.7.1 Chemical composition

<table>
<tr><th rowspan="2">Type of steel</th><th rowspan="2">Tensile strength N/mm²</th><th colspan="8">Chemical composition of ladle samples %</th></tr>
<tr><th>C max.</th><th>Si</th><th>Mn</th><th>P max.</th><th>S max.</th><th>Al</th><th colspan="2">Residual elements</th></tr>
<tr><td rowspan="3">Carbon-manganese</td><td>410-530</td><td>0,20</td><td rowspan="3">0,10–0,40</td><td>0,50-1,20</td><td rowspan="3">0,030</td><td rowspan="3">0,025</td><td rowspan="3">(See Notes 1 and 3)</td><td colspan="2" rowspan="3">Ni 0,40 max.
Cr 0,25 max.
Mo 0,10 max.
Cu 0,30 max.
Total 0,80 max.</td></tr>
<tr><td>450-580</td><td>0,23</td><td>0,80-1,40</td></tr>
<tr><td>490-610</td><td>0,25</td><td>0,90-1,70</td></tr>
<tr><td rowspan="3">Alloy steel</td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td>Cr</td><td>Mo</td></tr>
<tr></tr>
<tr></tr>
<tr><td>1Cr1/2Mo</td><td>440–590</td><td>0,18</td><td rowspan="2">0,15–0,40</td><td rowspan="2">0,40–0,70</td><td rowspan="2">0,030</td><td rowspan="2">0,025</td><td rowspan="2">0,020 max.
(See Note 2)</td><td>0,85–1,15</td><td>0,45–0,65</td></tr>
<tr><td>21/4 Cr1Mo</td><td>440–590</td><td>0,15</td><td>2,0–2,5</td><td>0,90–1,20</td></tr>
</table>

Note 1. Fine grained steels are to contain:
aluminium (acid soluble) 0,015% min. or
aluminium (total) 0,018% min.

Note 2. For alloy steels, aluminium (acid soluble) 0,020% max.
The determination of the aluminium (total) content is acceptable provided the above value is not exceeded.

Note 3. Niobium may be used as a grain refiner in place of aluminium, in which case the content is to be in the range 0,01% to 0,06%.

7.4.2 On seamless drums and headers which are initially forged with open ends, test material is to be provided at each end of each forging. Where forged with one solid end, test material is to be provided at the open end only. Except where the ends are to be subsequently closed by forging, the test material is not to be removed until heat treatment has been completed. Where the ends are to be closed, rings of test material are to be cut off prior to the closing operation and are to be heat treated with the finished forging. In all cases, the test specimens are to be cut in the circumferential direction.

7.4.3 Unless otherwise agreed, tensile test specimens are to be taken with their axis at approximately 12,5 mm below the surface of the forging.

7.4.4 Small forgings may be batch tested in accordance with *Ch 5, 1.6 Test material 1.6.4* provided that hardness tests are carried out on each forging. In such cases, the mass of each forging is not to exceed 1 tonne and that of the batch is not to exceed 10 tonnes and the hardness values are to accord with *Table 5.7.2 Mechanical properties for acceptance purposes*.

7.4.5 If required by the Surveyors or by the Fabricators, test material may be given a simulated stress relieving heat treatment prior to the preparation of the test specimens. This has to be stated on the order, together with agreed details of the simulated heat treatment and the mechanical properties which can be expected.

7.4.6 Except as provided in *Ch 5, 7.4 Mechanical tests 7.4.7*, the results of all tensile tests are to comply with the requirements given in *Table 5.7.2 Mechanical properties for acceptance purposes* appropriate to the specified minimum tensile strength.

7.4.7 Where tests are taken at a depth greater than 12,5 mm from the surface or where they are taken in a transverse direction, the mechanical properties which can be expected are to be agreed.

7.4.8 On seamless drums and headers where tests are taken from each end, the variation in tensile strength is not to exceed 70 N/mm^2.

7.4.9 For small batch-tested forgings, the hardness values are to comply with the requirements of *Table 5.7.2 Mechanical properties for acceptance purposes* appropriate to the specified minimum tensile strength. If forgings of more than one thickness are to be supplied from one cast, then the test is to be made on the thickest forging.

7.5 Non-destructive examination

7.5.1 Non-destructive testing is to be carried out in accordance with the requirements of the approved forging drawing and specification, or as otherwise agreed between the manufacturer, purchaser and Surveyor.

7.6 Pressure tests

7.6.1 Where applicable, pressure tests are to be carried out in accordance with the requirements of the relevant Rules.

7.7 Mechanical properties for design purposes

7.7.1 Nominal values for the minimum lower yield or 0,2 per cent proof stress at temperatures of 50°C and higher are given in *Table 5.7.3 Mechanical properties for design purposes*. These values are intended for design purposes only, and verification is not required except for materials complying with National or proprietary specifications where the elevated temperature properties used for design purposes are higher than those given in *Table 5.7.3 Mechanical properties for design purposes*.

Table 5.7.2 Mechanical properties for acceptance purposes

Type of steel	Diameter or equivalent thickness	Yield stress N/mm^2	Tensile strength N/mm^2	Elongation on $565\sqrt{S_o}$ % minimum	Hardness Brinell
Carbon-manganese not specifically fine grained	≤100	215	410 – 530	20	110 – 155
	>100 ≤500	205			
	≤100	245	460 – 580	18	130 – 170
	>100	235			
	≤100	265	490 – 610	16	140 – 180
	>100	255			
Carbon-manganese, fine grained	≤100	235	410 – 530	20	110 – 155
	>100 ≤250	220			
	≤100	275	460 – 580	18	130 – 170
	>100 ≤250	255			
	≤100	305	490 – 610	16	140 – 180
	>100 ≤250	280			
Alloy steel					
1Cr 1/2Mo	—	275	440 – 590	19	110 – 160
2 1/4Cr1Mo	—	275	490 – 640	18	140 – 185

Table 5.7.3 Mechanical properties for design purposes

Type of steel	Diameter or equivalent thickness mm	Tensile strength N/mm^2	Nominal minimum lower yield or 0,2% proof stress N/mm^2											
			Temperature °C											
			50	100	150	200	250	300	350	400	450	500	550	600
Carbon-manganese not specifically fine grained	≤100	410–530	196	192	188	181	168	150	142	138	136	–	–	–
	>100		183	178	175	170	162	150	142	138	136	–	–	–
	≤100	460–580	227	222	218	210	194	176	168	162	158	–	–	–
	>100		212	206	203	197	188	176	168	162	158	–	–	–
	≤100	490–610	245	240	236	227	210	192	183	177	172	–	–	–
	>100		229	222	219	212	203	192	183	177	172	–	–	–
Carbon-manganese fine grained	≤100	410–530	222	215	204	188	171	152	141	134	130	–	–	–
	>100		207	200	190	175	164	152	141	134	130	–	–	–
	≤100	460–580	262	251	236	217	198	177	167	158	153	–	–	–
	>100		244	233	220	202	190	177	167	158	153	–	–	–
	≤100	490–610	286	272	256	234	213	192	182	173	168	–	–	–
	>100		266	253	238	218	205	192	182	173	168	–	–	–

Alloy steel 1Cr $^{1}/_{2}$Mo	—	410–560	254	241	224	213	197	184	170	162	157	151	146	145
2 $^{1}/_{4}$ Cr1Mo	—	490–640	268	261	253	245	236	230	224	218	205	189	167	145

7.7.2 Where verification is required, at least one tensile test at the proposed design or other agreed temperature is to be made on each forging or each batch of forgings. The test specimen is to be taken from material adjacent to that used for tests at ambient temperature, and the test procedure is to be in accordance with the requirements of *Ch 2 Testing Procedures for Metallic Materials*. The results of all tests are to comply with the requirements of the National or proprietary specification.

7.7.3 Values for the estimated average stress to rupture in 100 000 hours are given in *Table 5.7.4 Mechanical properties for design purposes: estimated average values for stress to rupture in 100 000 hours (units N/mm²)* and may be used for design purposes.

Table 5.7.4 Mechanical properties for design purposes: estimated average values for stress to rupture in 100 000 hours (units N/mm²)

Temperature °C	Grades of steel		
	Carbon-manganese	1Cr 1/2Mo	2 1/4 Cr1Mo
380	227	—	—
390	203	—	—
400	179	—	—
410	157	—	—
420	136	—	—
430	117	—	—
440	100	—	—
450	85	290	—
460	73	262	—
470	63	235	210
480	55	208	186
490	—	181	165
500	—	155	145
510	—	129	128
520	—	103	112
530	—	80	98
540	—	62	84
550	—	49	72
560	—	42	61
570	—	36	49
580	—	32	—
590	—	29	—

Section 8
Ferritic steel forgings for low temperature service

8.1 Scope

8.1.1 The requirements for carbon-manganese and nickel steels suitable for low temperature service are detailed in this Section. They are applicable to all forgings used for the construction of cargo tanks, storage tanks and process pressure vessels for liquefied gases and, where the design temperature is less than 0°C, to forgings for the piping systems.

8.1.2 The requirements are also applicable to forgings for other pressure vessels and pressure piping systems where the use of steels with guaranteed impact properties at low temperatures is required.

8.1.3 In all cases, details of the proposed chemical composition, heat treatment and mechanical properties are to be submitted for approval.

8.1.4 In addition to the steels in this Section, the austenitic stainless steels detailed in *Ch 5, 9 Stainless steel forgings* may also be used for low temperature applications.

8.2 Chemical composition

8.2.1 The chemical composition of ladle samples is, in general, to comply with the requirements given in *Table 5.8.1 Chemical composition of ferritic steel forgings*.

8.3 Heat treatment

8.3.1 Forgings are to be normalised, normalised and tempered or quenched and tempered in accordance with the approved specification.

8.4 Mechanical tests

8.4.1 At least one tensile and three Charpy V-notch impact test specimens are to be taken from each forging or each batch of forgings. Where the dimensions and shape allow, the test specimens are to be cut in a longitudinal direction.

8.4.2 The impact tests are to be carried out at a temperature appropriate to the type of steel and for the proposed application. Where forgings are intended for ships for liquefied gases, the test temperature is to be in accordance with the requirements given in *Ch 3, 6.4 Mechanical tests 6.4.6* in *Ch 3 Rolled Steel Plates, Strip, Sections and Bars*.

8.4.3 The results of all tensile tests are to comply with the approved specification.

8.4.4 The average energy values for impact tests are also to comply with the approved specification and generally with the requirements of *Ch 3, 6 Ferritic steels for low temperature service*. One individual value may be less than the required average value provided that it is not less than 70 per cent of this value. *See Ch 2, 1.4 Re-testing procedures* for re-test procedures.

8.5 Non-destructive examination

8.5.1 Non-destructive testing is to be carried out in accordance with the requirements of the approved forging drawing and specification, or as otherwise agreed between the manufacturer, purchaser and Surveyor.

8.6 Pressure tests

8.6.1 When applicable, pressure tests are to be carried out in accordance with the requirements of the relevant Rules.

Table 5.8.1 Chemical composition of ferritic steel forgings

<table>
<tr><th rowspan="2">Grade of steel</th><th rowspan="2">C %</th><th rowspan="2">Si %</th><th rowspan="2">Mn %</th><th rowspan="2">Ni %</th><th rowspan="2">P %</th><th rowspan="2">S %</th><th rowspan="2">Residual elements %</th><th colspan="2">Grain refiners %</th></tr>
<tr><th>Al</th><th>Other</th></tr>
<tr><td>LT–AH (AH40)
LT–DH (DH40)
LT–EH (EH40)</td><td>0,18 max.</td><td rowspan="2">0,50 max.</td><td rowspan="2">0,90 – 1,60</td><td>0,40 max.</td><td>0,035 max.</td><td>0,030 max.</td><td rowspan="2">Cu 0,35 max. Cr 0,25 max. Mo 0,08 max.
Total 0,60 max.</td><td rowspan="6">Total 0,020 min.
Acid soluble 0,015 min.</td><td rowspan="2">(See Note)
Nb 0,02 – 0,05 V 0,03 – 0,10 Ti 0,02 max.</td></tr>
<tr><td>LT–FH (FH40)</td><td>0,16 max.</td><td>0,80 max.</td><td rowspan="5">0,025 max.</td><td>0,025 max.</td></tr>
<tr><td>1 $^{1}/_{2}$Ni</td><td>0,18 max.</td><td rowspan="4">0,10–0,35</td><td>0,30 – 1,50</td><td>1,30 – 1,70</td><td rowspan="4">0,020 max.</td><td rowspan="4">Cu 0,35 max. Cr 0,25 max. Mo 0,08 max.
Total 0,60 max.</td><td rowspan="4"></td></tr>
<tr><td>3 $^{1}/_{2}$Ni</td><td>0,15 max.</td><td rowspan="3">0,30 – 0,90</td><td>3,20 – 3,80</td></tr>
<tr><td>5Ni</td><td>0,12 max.</td><td>4,70 – 5,30</td></tr>
<tr><td>9 Ni</td><td>0,10 max.</td><td>8,50 – 10,0</td></tr>
<tr><td colspan="10">Note The steel is to contain aluminium, niobium, vanadium or other suitable grain refining elements, either singly or in any combination. When used singly, the steel is to contain the specified minimum content of the grain refining element. When used in combination, the specified minimum content of each element is not applicable.</td></tr>
</table>

Section 9
Stainless steel forgings

9.1 General

9.1.1 Forgings in austenitic and duplex stainless steels are acceptable for use in the construction of cargo tanks, storage tanks and piping systems for chemicals and liquefied gases. They may also be accepted for elevated temperature service in boilers.

9.1.2 Where it is proposed to use forgings in these types of steels, details of the chemical composition, heat treatment and mechanical properties are to be submitted for approval. These are to comply, in general, with the requirements of *Ch 3, 7 Austenitic and duplex stainless steels* for austenitic steel plates.

9.2 Chemical composition

9.2.1 The chemical composition of ladle samples is to comply with the requirements given in *Table 5.9.1 Chemical composition of stainless steel forgings*.

9.2.2 Consideration will be given to the use of steels whose compositions are outside the scope of *Table 5.9.1 Chemical composition of stainless steel forgings*.

9.3 Heat treatment

9.3.1 All materials are to be supplied in the solution treated condition.

9.4 Mechanical tests

9.4.1 Tensile test specimens are to be taken in accordance with the appropriate requirements of *Ch 5, 1.7 Mechanical tests*.

9.4.2 The results of all tensile tests and impact tests are to comply with the requirements of *Table 5.9.2 Mechanical properties for acceptance purposes: stainless steel forgings* or the approved specification.

9.4.3 For austenitic stainless steel forgings, impact tests may be omitted subject to prior agreement with LR.

9.5 Mechanical properties for design purposes

9.5.1 Where austentic stainless steel forgings are intended for service at elevated temperatures, the nominal values for the minimum one per cent proof stress at temperatures of 100°C and higher given in *Table 5.9.3 Mechanical properties for design purposes: austenitic stainless steels* may be used for design purposes. Verification of these values is not required except for material complying with a National or proprietary specification in which the elevated temperature properties proposed for design purposes are higher than those given in *Table 5.9.3 Mechanical properties for design purposes: austenitic stainless steels*.

9.6 Non-destructive examination

9.6.1 Non-destructive examination is to be carried out in accordance with the requirements of the approved forging drawing and specification or as otherwise agreed between the manufacturer, purchaser and Surveyor.

9.7 Corrosion tests

9.7.1 Where corrosive conditions are anticipated in service, for grades 304, 316 and 317 intergranular corrosion tests are required in accordance with *Ch 2, 9.1 Intergranular corrosion test*. Such tests may also be required for grades 304L, 316L and 347.

9.7.2 Where corrosive conditions are anticipated in service, for duplex stainless grades pitting corrosion tests are required in accordance with *Ch 2, 9.2 Pitting corrosion test* . Unless otherwise specified, the test temperatures shall be 20°C for S31803 and 30°C for S32750.

Table 5.9.1 Chemical composition of stainless steel forgings

Type of steel	Chemical composition % (*see* Note)								
	C	Si	Mn	S	P	Cr	Mo	Ni	Others
Austenitic									
304L	0,03	1,000	2,000	0,030	0,045	18,0–20,0	-	8,0–13,0	-
304	0,08					18,0–20,0	-	8,0–11,0	-
316L	0,03					16,0–18,0	2,0–3,0	10,0–15,0	
316	0,08					16,0–18,0	2,0–3,0	10,0–14,0	
317	0,08					18,0–20,0	3,0–4,0	11,0–15,0	
347	0,08					17,0–20,0	–	9,0–13,0	Nb >10xC ≤1,10
Duplex									
UNS S 31803	0,03	1,00	2,00	0,020	0,030	21,0–23,0	2,5–3,5	4,5–6,5	N 0,08–0,20
UNS S 32750	0,03	0,80	1,20	0,020	0,035	24,0–26,0	3,0–5,0	6,0–8,0	N 0,24–0,32 Cu 0,50
Note Where a single value is shown (and not a range of values), the value is to be taken as maximum.									

Table 5.9.2 Mechanical properties for acceptance purposes: stainless steel forgings

Type of steel	Tensile strength N/mm^2 minimum	1,0% proof stress N/mm^2 minimum	Elongation on 5,65 √So % minimum	Reduction of area % minimum	Charpy V-notch impact tests	
					Test temperature °C	Average energy J
Austenitic						

304L	485	170	30	50	–196	41
304	515	205				
316L	485	170				
316	515	205				
317	515	205				
347	515	205				
Duplex						
UNS S 31803	620	450	25	45	–20	41
UNS S 32750	800	550	15	40		

Table 5.9.3 Mechanical properties for design purposes: austenitic stainless steels

Grade	Nominal 1% proof stress (N/mm^2) at a temperature of												
	100°C	150°C	200°C	250°C	300°C	350°C	400°C	450°C	500°C	550°C	600°C	650°C	700°C
304L	168	150	137	128	122	116	110	108	106	102	100	96	93
316L	177	161	149	139	133	127	123	119	115	112	110	107	105
316LN	238	208	192	180	172	166	161	157	152	149	144	142	138
321	192	180	172	164	158	152	148	144	140	138	135	130	124
347	204	192	182	172	166	162	159	157	155	153	151	—	—

Contents

Chapter 6

■ *Section 1* General requirements

1.1 Scope

1.1.1 This Section gives the general requirements for boiler tubes, superheater tubes and pipes intended for use in the construction of boilers, pressure vessels and pressure piping systems.

1.1.2 In addition to specifying mechanical properties for the purpose of acceptance testing, these requirements give details of appropriate mechanical properties at elevated temperatures to be used for design purposes.

1.1.3 Except for pipes for Class III pressure systems (as defined in the relevant Rules), all pipes and tubes are to be manufactured and tested in accordance with the requirements of *Ch 1 General Requirements* and *Ch 2 Testing Procedures for Metallic Materials*, the general requirements of this Section and the appropriate specific requirements given in *Ch 6, 2 Seamless pressure pipes*, *Ch 6, 3 Welded pressure pipes*, *Ch 6, 4 Ferritic steel pressure pipes for low temperature service*, *Ch 6, 5 Stainless steel pressure pipes* and *Ch 6, 6 Boiler and superheater tubes*.

1.1.4 Steels intended for the piping systems for liquefied gases where the design temperature is less than 0°C are to comply with the specific requirements of *Ch 6, 4 Ferritic steel pressure pipes for low temperature service* or *Ch 6, 5 Stainless steel pressure pipes*.

1.1.5 As an alternative to *Ch 6, 1.1 Scope 1.1.3* and *Ch 6, 1.1 Scope 1.1.4*, pipes or tubes which comply with National or proprietary specifications may be accepted provided that these specifications give reasonable equivalence to the requirements of this Chapter or alternatively are approved for a specific application. Generally, survey and certification are to be carried out in accordance with the requirements of *Ch 1 General Requirements*.

1.1.6 At the discretion of the Surveyor, a modified testing procedure may be adopted for small quantities of materials. In such cases, these may be accepted on the manufacturer's declared chemical composition and hardness tests or other evidence of satisfactory properties.

1.1.7 Pipes for Class III pressure systems are to be manufactured and tested in accordance with the requirements of an acceptable National specification. The manufacturer's test certificate will be acceptable and is to be provided for each consignment of material. Forge butt welded pipes are not acceptable for fuel oil systems, heating coils in oil tanks, primary refrigerant systems and other applications where the pressure exceeds 4,0 bar (4,1 kgf/cm^2).

1.2 Manufacture

1.2.1 Pipes for Class I and II pressure systems, boiler and superheater tubes are to be manufactured at works approved by Lloyd's Register (hereinafter referred as 'LR'). The steel used is to be manufactured and cast in ingot moulds or by an approved continuous casting process as detailed in *Ch 3, 1.4 Manufacture*.

1.2.2 Unless a particular method is requested by the purchaser, pipes and tubes may be manufactured by any of the following methods:

- Hot finished seamless.
- Cold finished seamless.
- Electric resistance or induction welded.

- Cold finished electric resistance or induction welded.
- Electric fusion welded.

1.2.3 Care is to be taken during manufacture that the pipe or tube surfaces coming in contact with any non-ferrous metals or their compounds are not contaminated to such an extent as could prove harmful during subsequent fabrication and operation.

1.3 Quality

1.3.1 All pipes and tubes are to have a workmanlike finish and are to be clean and free from such surface and internal defects as can be established by the specified tests.

1.3.2 All pipes and tubes are to be reasonably straight. The ends are to be cut nominally square with the axis of the pipe or tube, and are to be free from excessive burrs.

1.4 Dimensional tolerances

1.4.1 The tolerances on the wall thickness and diameter of pipes and tubes are to be in accordance with an acceptable National specification.

1.5 Chemical composition

1.5.1 The requirements for the chemical composition of ladle samples and acceptable methods of deoxidation are detailed in subsequent Sections in this Chapter.

1.6 Heat treatment

1.6.1 All pipes and tubes are to be supplied in the condition detailed in the relevant specific requirements.

1.7 Test material

1.7.1 Pipes and tubes are to be presented for test in batches. The size of a batch and the number of tests to be performed are dependent on the application.

1.7.2 Where heat treatment has been carried out, a batch is to consist of pipes or tubes of the same size, manufactured from the same types of steel and subjected to the same finishing treatment in a continuous furnace, or heat treated together in the same batch type furnace.

1.7.3 Where no heat treatment has been carried out, a batch is to consist of pipes or tubes of the same size manufactured by the same method from material of the same type of steel.

1.7.4 For pipes for Class I pressure systems and boiler and superheater tubes, at least two per cent of the number of lengths in each batch is to be selected at random for the preparation of tests at ambient temperature.

1.7.5 For pipes for Class II pressure systems, each batch is to contain not more than the number of lengths given in *Table 6.1.1 Batch sizes for pipes for Class II pressure systems*. Tests are to be carried out on at least one pipe selected at random from each batch or part thereof.

Table 6.1.1 Batch sizes for pipes for Class II pressure systems

Outside diameter mm	Number in batch
≤323,9	200 pipes as made
>323,9	100 pipes as made

1.8 Dimensions of test specimens and test procedures

1.8.1 The procedures for mechanical tests and the dimensions of the test specimens are to be in accordance with *Ch 2 Testing Procedures for Metallic Materials*.

1.9 Visual and non-destructive testing

1.9.1 All pipes for Class I and II pressure systems, boiler and superheater tubes, are to be presented for visual examination and verification of dimensions. The manufacturer is to provide adequate lighting conditions to enable an internal and external examination of the pipes and tubes to be carried out.

1.9.2 For welded pipes and tubes, the manufacturer is to employ suitable non-destructive methods for the quality control of the welds. It is preferred that this examination is carried out on a continuous basis.

1.10 Hydraulic test

1.10.1 Each pipe and tube is to be subjected to a hydraulic test at the manufacturer's works.

1.10.2 The hydraulic test pressure is to be determined from the following formula, except that the maximum test pressure need not exceed 140 bar (143 kgf/cm^2):

$$P = \frac{20st}{D}\left(P = \frac{200st}{D}\right)$$

where

P = test pressure, in bar (kgf/cm^2)

D = nominal outside diameter, in mm

t = nominal wall thickness, in mm

s = 80 per cent of the specified minimum yield stress, in N/mm^2 (kgf/mm^2), for ferritic steels and 70 per cent of the specified minimum, 1,0 per cent proof stress, in N/mm^2 (kgf/mm^2), for austenitic steels. These relate to the values specified for acceptance testing at ambient temperature.

1.10.3 The test pressure is to be maintained for sufficient time to permit proof and inspection. Unless otherwise agreed, the manufacturer's certificate of satisfactory hydraulic test will be accepted. Where it is proposed to adopt a test pressure other than that determined as in *Ch 6, 1.10 Hydraulic test 1.10.2*, the proposal will be subject to special consideration.

1.10.4 Subject to special approval, either an ultrasonic or eddy current test can be accepted in lieu of the hydraulic test.

1.11 Rectification of defects

1.11.1 Surface imperfections may be removed by grinding provided that the thickness of the pipe or tube after dressing is not less than the required minimum thickness. The dressed area is to be blended into the contour of the tube.

1.11.2 By agreement with the Surveyor, the repair of minor defects by welding can be accepted, subject to welding procedure tests which demonstrate acceptable properties appropriate for the grade of pipe to be repaired. Weld procedure tests are to be subjected to the same heat treatment as will be applied to the actual pipes after weld repair.

1.11.3 The repaired area is to be tested by magnetic particle examination, or, for austenitic steels, by liquid penetrant examination on completion of welding, heat treatment and surface grinding.

1.12 Identification

1.12.1 Pipes and tubes are to be clearly marked by the manufacturer in accordance with the requirements of *Ch 1 General Requirements*. The following details are to be shown on all materials which have been accepted:

(a) LR or Lloyd's Register.
(b) Manufacturer's name or trade mark.
(c) Identification mark for the specification or grade of steel.
(d) Identification number and/or initials which will enable the full history of the item to be traced.
(e) The personal stamp of the Surveyor responsible for the final inspection.

1.12.2 It is recommended that hard stamping be restricted to the end face, but it may be accepted in other positions in accordance with National Standards and practices.

1.13 Certification of materials

1.13.1 Unless a LR certificate is specified in other parts of the Rules, a manufacturer's certificate validated by LR is to be issued, *see Ch 1, 3.1 General*.

1.13.2 The manufacturer is to provide LR with the following information:

(a) Purchaser's name and order number.
(b) If known, the contract number for which the material is intended.
(c) Address to which material is despatched.
(d) Specification or the grade of material.
(e) Description and dimensions.
(f) Identification number and/or initials.

(g) Cast number and chemical composition of ladle samples.
(h) Mechanical test results, and results of the intercrystalline corrosion tests where applicable.
(i) Condition of supply.

1.13.3 As a minimum, the chemical composition stated on the certificate is to include the content of all the elements detailed in the specific requirements. Where rimming steel is supplied, this is to be stated on the certificate.

1.13.4 When steel is not produced at the pipe or tube mill, a certificate is to be supplied by the steelmaker stating the process of manufacture, the cast number and the ladle analysis.

1.13.5 The steel manufacturer's works is to be approved by LR.

■ *Section 2* Seamless pressure pipes

2.1 Scope

2.1.1 Provision is made in this Section for seamless pressure pipes in carbon, carbon-manganese and low alloy steels.

2.1.2 Where pipes are used for the manufacture of pressure vessel shells and headers, the requirements for forgings in *Ch 5, 7 Forgings for boilers, pressure vessels and piping systems* are applicable where the wall thickness exceeds 40 mm.

2.2 Manufacture and chemical composition

2.2.1 Pipes are to be manufactured by a seamless process and may be hot or cold finished.

2.2.2 The method of deoxidation and the chemical composition of ladle samples are to comply with the appropriate requirements given in *Table 6.2.1 Chemical composition of seamless pressure pipes*.

Table 6.2.1 Chemical composition of seamless pressure pipes

<table>
<tr><th rowspan="2">Type of steel</th><th rowspan="2">Grade</th><th rowspan="2">Method of deoxidation</th><th colspan="12">Chemical composition of ladle samples %</th></tr>
<tr><th>C</th><th>Si</th><th>Mn</th><th>S max.</th><th>P max.</th><th colspan="7">Residual elements</th></tr>
<tr><td rowspan="5">Carbon and carbon-manganese</td><td>320</td><td rowspan="2">Semi-killed or killed</td><td>≤0,16</td><td>—</td><td>0,40—0,70</td><td>0,050</td><td>0,050</td><td colspan="7" rowspan="5">Ni 0,30 max.
Cr 0,25 max.
Mo 0,10 max.
Cu 0,30 max.
Total 0,70 max.</td></tr>
<tr><td>360</td><td>≤0,17</td><td>≤0,35</td><td>0,40—0,80</td><td>0,045</td><td>0,045</td></tr>
<tr><td>410</td><td rowspan="3">Killed</td><td>≤0,21</td><td>≤0,35</td><td>0,40—1,20</td><td>0,045</td><td>0,045</td></tr>
<tr><td>460</td><td>≤0,22</td><td>≤0,35</td><td>0,80—1,40</td><td>0,045</td><td>0,045</td></tr>
<tr><td>490</td><td>≤0,23</td><td>≤0,35</td><td>0,80—1,50</td><td>0,045</td><td>0,045</td></tr>
<tr><td rowspan="2">1Cr$^{1}/_{2}$Mo</td><td rowspan="2">440</td><td rowspan="2">Killed</td><td rowspan="2">0,10 – 0,18</td><td rowspan="2">0,10 – 0,35</td><td rowspan="2">0,40—0,70</td><td rowspan="2">0,040</td><td rowspan="2">0,040</td><td>Ni</td><td>Cr</td><td>Mo</td><td>Cu</td><td>Sn</td><td>V</td><td>Al</td></tr>
<tr><td>0,30 max.</td><td>0,70 – 1,10</td><td>0,45 – 0,65</td><td>0,25 max.</td><td>0,03 max.</td><td>—</td><td>≤0,020</td></tr>
</table>

$2^1/_4$Cr1Mo	410 490	Killed	0,08 – 0,15	0,10 – 0,50	0,40 — 0,70	0,040	0,040	0,30 max.	2,0— 2,5	0,90— 1,20	0,25 max.	0,03 max.	—	≤0,020
$^1/_2$Cr$^1/_2$Mo$^1/_4$V	460	Killed	0,10 – 0,18	0,10 – 0,35	0,40 — 0,70	0,040	0,040	0,30	0,30— 0,60	0,50— 0,70	0,25 max.	0,03 max.	0,22— 0,32	≤0,020

2.3 Heat treatment

2.3.1 Pipes are to be supplied in the condition given in *Table 6.2.2 Heat treatment*.

2.4 Mechanical tests

2.4.1 All pipes are to be presented in batches as defined in *Ch 6, 1 General requirements*.

2.4.2 Each pressure pipe selected for test is to be subjected to tensile and flattening or bend tests.

2.4.3 The results of all mechanical tests are to comply with the appropriate requirements given in *Table 6.2.3 Mechanical properties for acceptance purposes: seamless pressure pipes (maximum wall thickness 40 mm), see 2.1.2* .

2.5 Mechanical properties for design

2.5.1 Values for nominal minimum lower yield or 0,2 per cent proof stress at temperatures of 50°C and higher are given in *Table 6.2.4 Mechanical properties for design purposes: seamless pressure pipes* and are intended for design purposes only. Verification of these values is not required, except for materials complying with National or proprietary specification where the elevated temperature properties used for design are higher than those given in *Table 6.2.4 Mechanical properties for design purposes: seamless pressure pipes*.

2.5.2 In such cases, at least one tensile test at the proposed design or other agreed temperature is to be made on each cast. The test specimen is to be taken from material adjacent to that used for tests at ambient temperature and tested in accordance with the procedures given in *Ch 2 Testing Procedures for Metallic Materials*. If tubes or pipes of more than one thickness are supplied from one cast, the test is to be made on the thickest tube or pipe.

Table 6.2.2 Heat treatment

Type of steel		Condition of supply
Carbon and carbon-manganese		
Hot finished		Hot finished (*see* Note 1) Normalised (*see* Note 2)
Cold finished		Normalised (*see* Note 2)
Alloy steel		
1Cr$^1/_2$Mo		Normalised and tempered
$2^1/_4$Cr1Mo	Grade 410	Fully annealed
	Grade 490	Normalised and tempered 650—780°C
	Grade 490	Normalised and tempered 650—750°C
$^1/_2$Cr$^1/_2$Mo$^1/_4$V		Normalised and tempered
Note 1. Provided that the finishing temperature is sufficiently high to soften the material.		
Note 2. Normalised and tempered at the option of the manufacturer.		

2.5.3 As an alternative to *Ch 6, 2.5 Mechanical properties for design 2.5.2*, a manufacturer may carry out an agreed comprehensive test program for a stated grade of steel to demonstrate that the specified minimum mechanical properties at elevated temperatures can be consistently obtained. This test program is to be carried out under the supervision of the Surveyors, and the results submitted for assessment and approval. When a manufacturer is approved on this basis, tensile tests at elevated

temperatures are not required for acceptance purposes, but at the discretion of the Surveyors occasional check tests of this type may be requested.

2.5.4 Values for the estimated average stress to rupture in 100 000 hours are given in *Table 6.2.5 Mechanical properties for design purposes: seamless pressure pipes - Estimated values for stress to rupture in 100,000 hours (units N/mm²)* and may be used for design purposes.

Table 6.2.3 Mechanical properties for acceptance purposes: seamless pressure pipes (maximum wall thickness 40 mm), *see* 2.1.2

Type of steel	Grade	Yield stress N/mm²	Tensile strength N/mm²	Elongation on 5,65 $\sqrt{S_0}$ % minimum	Flattening test constant *C*	Bend test diameter of former (*t* = thickness)
Carbon and carbon-manganese	320	195	320—440	25	0,10	4*t*
	360	215	360—480	24	0,10	
	410	235	410—530	22	0,08	
	460	265	460—580	21	0,07	
	490	285	490—610	21	0,07	
$1Cr^1/_2Mo$	440	275	440—590	22	0,07	4*t*
$2^1/_4Cr1Mo$	410 (see Note 1)	135	410—560	20	0,07	4*t*
	490 (see Note 2)	275	490—640	16		
$^1/_2Cr^1/_2Mo^1/_4V$	460	275	460—610	15	0,07	4*t*

Note 1. Annealed condition.

Note 2. Normalised and tempered condition.

Table 6.2.4 Mechanical properties for design purposes: seamless pressure pipes

Type of steel	Grade	Nominal minimum lower yield or 0,2% proof stress N/mm² — Temperature °C 50	100	150	200	250	300	350	400	450	500	550	600
Carbon and carbon-manganese	320	172	168	158	147	125	100	91	88	87	—	—	—
	360	192	187	176	165	145	122	111	109	107	—	—	—
	410	217	210	199	188	170	149	137	134	132	—	—	—
	460	241	234	223	212	195	177	162	159	156	—	—	—
	490	256	249	237	226	210	193	177	174	171	—	—	—
$1Cr^1/_2Mo$	440	254	240	230	220	210	183	169	164	161	156	151	—
$2^1/_2Cr1Mo$	410 (*see* Note 1)	121	108	99	92	85	80	76	72	69	66	64	62
	490 (*see* Note 2)	268	261	253	245	236	230	224	218	205	189	167	145

$^{1}/_{2}$Cr$^{1}/_{2}$Mo$^{1}/_{4}$V	460	266	259	248	235	218	192	184	177	168	155	148	—

Note 1. Annealed condition.

Note 2. Normalised and tempered condition.

Table 6.2.5 Mechanical properties for design purposes: seamless pressure pipes - Estimated values for stress to rupture in 100,000 hours (units N/mm^2)

Temperature °C	Carbon and carbon-manganese		$1Cr^{1}/_{2}Mo$	$2^{1}/_{4}Cr1Mo$		$^{1}/_{2}Cr^{1}/_{2}Mo^{1}/_{4}V$
	Grade 320 360 410	Grade 460 490	Grade 440	Grade 410 Annealed	Grade 490 Normalised and tempered (*see* Note)	Grade 460
380	171	227	—	—	—	—
390	155	203	—	—	—	—
400	141	179	—	—	—	—
410	127	157	—	—	—	—
420	114	136	—	—	—	—
430	102	117	—	—	—	—
440	90	100	—	—	—	—
450	78	85	—	196	221	—
460	67	73	—	182	204	—
470	57	63	—	168	186	—
480	47	55	210	154	170	218
490	36	47	177	141	153	191
500	—	41	146	127	137	170
510	—	—	121	115	122	150
520	—	—	99	102	107	131
530	—	—	81	90	93	116
540	—	—	67	78	79	100
550	—	—	54	69	69	85
560	—	—	43	59	59	72
570	—	—	35	51	51	59
580	—	—	—	44	44	46

Note When the tempering temperature exceeds 750°C, the values for Grade 410 are to be used.

■ *Section 3*
Welded pressure pipes

3.1 Scope

3.1.1 Provision is made in this Section for welded pressure pipes in carbon, carbon-manganese and low alloy steels.

3.2 Manufacture and chemical composition

3.2.1 Pipes are to be manufactured by the electric resistance or induction welding process and, if required, may be subsequently hot reduced or cold finished.

3.2.2 Where it is proposed to use other welding processes, details of the welding processes and procedures are to be submitted for review.

3.2.3 In all cases, welding procedure tests are required. Test samples are to be subjected to the same heat treatment as the pipe.

3.2.4 The method of deoxidation and the chemical composition of ladle samples are to comply with the appropriate requirements given in *Table 6.3.1 Chemical composition of welded pressure pipes*.

3.3 Heat treatment

3.3.1 Pipes are to be supplied in the heat treated condition given in *Table 6.3.3 Heat treatment: welded pressure pipes*.

3.4 Mechanical tests

3.4.1 All pipes are to be presented in batches as defined in *Ch 6, 1 General requirements*.

3.4.2 Each pressure pipe selected for test is to be subjected to tensile and flattening or bend tests.

3.4.3 The results of all mechanical tests are to comply with the appropriate requirements given in *Table 6.3.2 Mechanical properties for acceptance purposes: welded pressure pipes*.

3.5 Mechanical properties for design

3.5.1 The mechanical properties at elevated temperature for carbon and carbon-manganese steels in Grades 320 to 460 and 1Cr½Mo steel can be taken from the appropriate Tables in *Ch 6, 2 Seamless pressure pipes*.

Table 6.3.1 Chemical composition of welded pressure pipes

Type of steel	Grade	Method of deoxidation	Chemical composition of ladle samples %					
			C	Si	Mn	S max.	P max.	Residual elements
Carbon and carbon-manganese	320	Any method (*see* Note)	≤0,16	–	0,30–0,70	0,050	0,050	Ni 0,30 max. Cr 0,25 max. Mo 0,10 max. Cu 0,30 max. Total 0,70 max.
	360		≤0,17	≤0,35	0,40–1,00	0,045	0,045	
	410	Killed	≤0,21	≤0,35	0,40–1,20	0,045	0,045	
	460		≤0,22	≤0,35	0,80–1,40	0,045	0,045	

1Cr$^1/_2$Mo	440	Killed	0,10 – 0,18	0,10 – 0,35	0,40– 0,70	0,040	0,040	Ni	Cr	Mo	Cu	Sn	Al
								0,30 max.	0,70– 1,10	0,45– 0,65	0,25 max.	0,03 max.	≤0,020
Note For rimming steels, the carbon content may be increased to 0,19% max.													

Table 6.3.2 Mechanical properties for acceptance purposes: welded pressure pipes

Type of steel	Grade	Yield stress N/mm^2	Tensile strength N/mm^2	Elongation on 5,65 $\sqrt{S_0}$ % minimum	Flattening test constant *C*
Carbon and carbon-manganese	320	195	320 – 440	25	0,10
	360	215	360 – 480	24	0,10
	410	235	410 – 530	22	0,08
	460	265	460 – 580	21	0,07
1Cr$^1/_2$Mo	440	275	440 – 590	22	0,07

Table 6.3.3 Heat treatment: welded pressure pipes

Type of steel	Condition of supply
Carbon and carbon-manganese, *see* Note	Normalised (Normalised and tempered at the option of the manufacturer)
1Cr$^1/_2$Mo	Normalised and tempered
Note Subject to special approval, electric resistance welded (ERW) pipes and tubes in grades 320 and 360 may be supplied without heat treatment for the following applications: **Note** (a) Class 2 piping systems, except for liquefied gases or other low temperature applications. **Note** (b) Class 3 piping systems.	

■ *Section 4*
Ferritic steel pressure pipes for low temperature service

4.1 Scope

4.1.1 Provision is made in this Section for carbon, carbon-manganese and nickel pipes intended for use in the piping arrangements for liquefied gases where the design temperature is less than 0°C. These requirements are also applicable for other types of pressure piping systems where the use of steels with guaranteed impact properties at low temperatures is required.

4.2 Manufacture and chemical composition

4.2.1 Carbon and carbon-manganese steel pipes are to be manufactured by a seamless, electric resistance or induction welding process.

4.2.2 Nickel steel pipes are to be manufactured by a seamless process.

4.2.3 Seamless pipes may be hot finished or cold finished. Welded pipes may be as-welded, hot finished or cold finished. The terms `hot finished', `cold finished' and `as-welded' apply to the condition of the pipes before final heat treatment.

4.2.4 The method of deoxidation and the chemical composition of ladle samples are to comply with the appropriate requirements given in *Table 6.4.1 Chemical composition*.

4.3 Heat treatment

4.3.1 Pipes are to be supplied in the condition given in *Table 6.4.3 Heat treatment*.

4.4 Mechanical tests

4.4.1 All pipes are to be presented for test in batches as defined in *Ch 6, 1 General requirements* for Class 1 pressure piping systems, but in addition the material in each batch is to be from the same cast.

4.4.2 At least two per cent of the number of lengths in each batch is to be selected at random for the preparation of tests.

4.4.3 Each pressure pipe selected for test is to be subjected to tensile, flattening or bend test at room temperature and, where the wall thickness is 6 mm or greater, an impact test at the test temperature specified in *Table 6.4.2 Mechanical properties for acceptance purposes*.

4.4.4 The impact tests are to consist of a set of three Charpy V-notch test specimens cut in the longitudinal direction with the notch perpendicular to the original surface of the pipe. The dimensions of the test specimens are to be in accordance with the requirements of *Ch 2 Testing Procedures for Metallic Materials*.

4.4.5 The results of all tensile, flattening and bend tests are to comply with the appropriate values in *Table 6.4.2 Mechanical properties for acceptance purposes*.

4.4.6 The average value for impact test specimens is to comply with the appropriate requirements of *Table 6.4.2 Mechanical properties for acceptance purposes*. One individual value may be less than the required average value provided that it is not less than 70 per cent of this value. *See Ch 2, 1.4 Re-testing procedures 1.4.1* for re-test procedures.

Table 6.4.1 Chemical composition

Type of steel	Grade	Method of deoxidation	Chemical composition of ladle sample %							
			C max.	Si	Mn	P max.	S max.	Ni	Al_{sol} *see* Note	Residual elements
Carbon	360	Fully killed	0,17	0,10—0,35	0,40—1,00	0,030	0,025	—	0,015 min.	Cr 0,25 Cu 0,30 Mo 0,10 Ni 0,30
Carbon-manganese	410 and 460		0,20	0,10—0,35	0,60—1,40	0,030	0,025	—	0,015 min.	Total 0,70
$3\frac{1}{2}$ Ni	440		0,15	0,15—0,35	0,30—0,90	0,025	0,020	3,25—3,75	—	Cr 0,25
										Cu 0,30 Mo 0,10
9Ni	690		0,13	0,15—0,30	0,30—0,90	0,025	0,020	8,50—9,50	—	Total 0,60
Note Where a minimum Al_{sol} of 0,015% is specified, the determination of the total aluminium is acceptable provided that the result is not less than 0,020%.										

Table 6.4.2 Mechanical properties for acceptance purposes

Type of steel	Grade	Yield stress N/mm^2	Tensile strength N/mm^2	Elongation on 5,65 $\sqrt{S_0}$ % minimum	Flattening test constant *C*	Bend test diameter of former (*t* = thickness)	Charpy V-notch impact tests	
							Test temperature °C	Average energy J minimum
Carbon	360	210	360—480	24	0,10	4*t*	–40	27
Carbon-manganese	410	235	410—530	22	0,08	4*t*	–50	27
	460	260	460—580	21	0,07			
3½Ni	440	245	440—590	16	0,08	4*t*	–95	34
9Ni	690	510	690—840	15	0,08	4*t*	–196	41

Note For standard subsidiary impact test specimens, the minimum energy values are to be as follows:

Required average energy value for standard 10 mm x 10 mm	Subsidiary 10 mm x 7,5 mm	Subsidiary 10 mm x 5 mm
	Average energy	Average energy
27 J	22 J	18 J
34 J	28 J	23 J
41 J	34 J	27 J

Table 6.4.3 Heat treatment

Type of steel	Condition of supply
Carbon and carbon-manganese	Hot finished Normalised Normalised and tempered
3$^1/_2$Ni	Normalised Normalised and tempered
9Ni	Double normalised and tempered Quenched and tempered

■ *Section 5*
Stainless steel pressure pipes

5.1 Scope

5.1.1 Provision is made in this Section for austenitic and duplex stainless steel pipes suitable for use in the construction of the piping systems for chemicals and for liquefied gases where the design temperature is not less than minus 165°C and for bulk chemical tankers.

5.1.2 Austenitic stainless steels may be suitable for service at elevated temperatures. Where such applications are proposed, details of the chemical composition, heat treatment and mechanical properties are to be submitted for consideration and approval.

5.1.3 Where it is intended to supply seamless pipes in the direct quenched condition, a programme of tests for approval is to be carried out under the supervision of the Surveyors, and the results are to be to the satisfaction of LR, *see Ch 1, 2.2 LR Approval – General*.

5.2 Manufacture and chemical composition

5.2.1 Pipes are to be manufactured by a seamless or a continuous automatic electric fusion welding process.

5.2.2 Welding is to be in a longitudinal direction, with or without the addition of filler metal.

5.2.3 The chemical composition of the ladle samples is to comply with the appropriate requirements of *Table 6.5.1 Chemical composition*.

5.3 Heat treatment

5.3.1 Pipes are generally to be supplied by the manufacturer in the solution treated condition over their full length.

5.3.2 Alternatively, seamless pipes may be direct quenched immediately after hot forming, while the temperature of the pipes is not less than the specified minimum solution treatment temperature.

5.4 Mechanical tests

5.4.1 All pipes are to be presented in batches as defined in *Ch 6, 1 General requirements* for Class I and II piping systems.

5.4.2 Each pipe selected for test is to be subjected to tensile and flattening or bend tests.

5.4.3 The results of all mechanical tests are to comply with the appropriate requirements given in *Table 6.5.2 Mechanical properties for acceptance purposes*.

Table 6.5.1 Chemical composition

Type of steel	Grade	Chemical composition %								
		C max.	Si	Mn	P max.	S max.	Cr	Mo	Ni	Others
Austenitic										
304L	490	0,030	≤1,00	≤2,00	0,045	0,030	18,0 – 20,0	–	8,0–12,0	N≤0,11
316L	490	0,030	≤1,00	≤2,00	0,045	0,030	16,0 – 18,5	2,0–3,0	10,0 – 14,0	–
317	490	0,08	≤1,00	≤2,00	0,045	0,030	18,0-20,0	3,0-4,0	11,0-15,0	–
321	510	0,08	≤1,00	≤2,00	0,045	0,030	17,0 – 19,0	—	9,0 – 12,0	Ti >5 x C ≤0,70
347	510	0,08	≤1,00	≤2,00	0,045	0,030	17,0 – 19,0	—	9,0 – 12,0	Nb >10 x C ≤1,10
Duplex										
UNS S31803	–	0,030	≤1,00	≤2,00	0,035	0,020	21,0–23,0	2,5–3,5	4,5–6,5	N 0,08-0,22
UNS S32750	–	0,030	≤0,80	≤1,20	0,035	0,020	24,0-26,0	3,0–5,0	6,0-8,0	N 0,24-0,32 Cu≤0,50

Table 6.5.2 Mechanical properties for acceptance purposes

Type of steel	Grade	0,2% proof stress N/mm^2 (see Note)	1,0% proof stress N/mm^2	Tensile strength N/mm^2	Elongation on 5,65 $\sqrt{S_o}$ % minimum	Flattening test constant C	Bend test diameter of former (*t* = thickness)
Austenitic							
304L	490	175	205	490 – 690	30	0,09	3*t*
316L	490	185	215	490 – 690	30	0,09	3*t*
317		185	205	490–690	30	0,09	3t
321	510	195	235	510 – 710	30	0,09	3*t*
347	510	205	245	510 – 710	30	0,09	3*t*
Duplex							
UNS S31803	-	450	–	620 minimum	25	0,09	3t
UNS S32750	-	550	–	800 minimum	15	0,09	3t
Note Except for the duplex stainless steel grades, the 0,2% proof stress values are given for information purposes and unless otherwise agreed are not required to be verified by test.							

5.5 Corrosion tests

5.5.1 For materials used for piping systems for chemicals, corrosion tests are to be carried out on one per cent of the number of pipes in each batch, with a minimum of one pipe. For austenitic stainless steels this should be an intercrystalline corrosion test (*see Ch 2, 9.1 Intergranular corrosion test*) and for duplex stainless steels this should be a pitting corrosion test (*see Ch 2, 9.2 Pitting corrosion test*). For the latter, the test temperatures shall be 20°C for S31803 and 30°C for S32750.

5.5.2 For pipes with an outside diameter not exceeding 40 mm, the test specimens are to consist of a full cross-section. For larger pipes, the test specimens are to be cut as circumferential strips of full wall thickness and having a width of not less than 12,5 mm. In both cases, the total surface area is to be between 15 and 35 cm^2.

5.5.3 Unless otherwise agreed or required for a particular chemical cargo, the testing procedure is to be in accordance with *Ch 2, 9 Corrosion tests* for austenitic stainless steels and *Ch 12, 3.3 Duplex stainless steels 3.3.3(c)* for duplex stainless steels.

5.5.4 After immersion, the full cross-section test specimens are to be subjected to a flattening test in accordance with the requirements of *Ch 2 Testing Procedures for Metallic Materials*. The strip test specimens are to be subjected to a bend test through 90° over a mandrel of diameter equal to twice the thickness of the test specimen.

5.6 Fabricated pipework

5.6.1 Fabricated pipework is to be produced from material manufactured in accordance with *Ch 6, 5.2 Manufacture and chemical composition*, *Ch 6, 5.3 Heat treatment*, *Ch 6, 5.4 Mechanical tests* and *Ch 6, 5.5 Corrosion tests*.

5.6.2 Welding is to be carried out in accordance with an approved and qualified procedure by suitably qualified welders.

5.6.3 Fabricated pipework may be supplied in the as-welded condition without subsequent solution treatment provided that welding procedure tests have demonstrated satisfactory material properties including resistance to intercrystalline corrosion (austenitic stainless steel) or pitting corrosion (duplex stainless steel).

5.6.4 In addition, butt welds are to be subjected to 5 per cent radiographic examination for Class I, and 2 per cent for Class II pipes.

5.6.5 Fabricated pipework in the as-welded condition and intended for systems located on deck is to be protected by a suitable corrosion control coating.

5.7 Certification of materials

5.7.1 Each test certificate is to be of the type and give the information detailed in *Ch 1, 3.1 General* together with general details of heat treatment and, where applicable, the results obtained from the appropriate corrosion tests. As a minimum, the chemical composition is to include the content of all the elements detailed in *Table 6.5.1 Chemical composition*.

Section 6
Boiler and superheater tubes

6.1 Scope

6.1.1 Provision is made in this Section for boiler and superheater tubes in carbon, carbon-manganese and low alloy steels.

6.1.2 Austenitic stainless steels may also be used for this type of service. Where such applications are proposed, details of the chemical composition, heat treatment and mechanical properties are to be submitted for consideration and approval.

6.2 Manufacture and chemical composition

6.2.1 Tubes are to be seamless or welded and are to be manufactured in accordance with the requirements of *Ch 6, 2 Seamless pressure pipes* and *Ch 6, 3 Welded pressure pipes*, respectively.

6.2.2 The method of deoxidation and the chemical composition of ladle samples are to comply with the requirements given in *Table 6.2.1 Chemical composition of seamless pressure pipes* or *Table 6.3.1 Chemical composition of welded pressure pipes*, as appropriate.

6.3 Heat treatment

6.3.1 All tubes are to be supplied in accordance with the requirements given in *Table 6.2.2 Heat treatment* or *Table 6.3.3 Heat treatment: welded pressure pipes* as appropriate, except that 1Cr½Mo steel may be supplied in the normalised only condition when the carbon content does not exceed 0,15 per cent.

6.4 Mechanical tests

6.4.1 Tubes are to be presented for test in batches as defined in *Ch 6, 1 General requirements*.

6.4.2 Each boiler and superheater tube selected for test is to be subjected to at least the following:

(a) Tensile test.
(b) Flattening or bending test.
(c) Expanding or flanging test.

6.4.3 The results of all mechanical tests are to comply with the appropriate requirements given in *Table 6.6.1 Mechanical properties for acceptance purposes: boiler and superheater tubes*.

6.5 Mechanical properties for design

6.5.1 The mechanical properties at elevated temperature for carbon and carbon-manganese steels in Grades 320 to 460, 1Cr½Mo and 2¼Cr1Mo steels can be taken from the appropriate Tables in *Ch 6, 2 Seamless pressure pipes*.

6.5.2 Where rimming steel is used, the design temperature is limited to 400°C.

Table 6.6.1 Mechanical properties for acceptance purposes: boiler and superheater tubes

Type of steel	Grade	Yield stress N/mm^2	Tensile strength N/mm^2	Elongation on 5,65 $\sqrt{S_0}$ % minimum	Flattening test constant *C*	Bend test diameter of former (*t* = thickness)	Drift expanding and flanging test minimum % increase in outside diameter		
							Ratio $\frac{Inside diameter}{Outside diameter}$		
							≤0,6	>0,6≤0,8	>0,8
Carbon and carbon-manganese	320	195	320–440	25	0,10	4*t*	12	15	19
	360	215	360–480	24	0,10		12	15	19
	410	235	410–530	22	0,08		10	12	17
	460	265	460–580	21	0,07		8	10	15
1Cr^1 /$_2$Mo	440	275	440–590	22	0,07	4*t*	8	10	15

$2^1/_2$Cr1Mo	410 (*see* Note 1)	135	410–560	20	0,07	4*t*	8	10	15
	490 (*see* Note 2)	275	490–640	16					

Note 1. Annealed condition.

Note 2. Normalised and tempered condition.

Contents

Iron Castings

Section 1
General requirements

1.1 Scope

1.1.1 This Section gives the general requirements for grey (flake), spheroidal (nodular) graphite and compacted (vermicular) graphite iron castings intended for use in the construction of ships, other marine structures, machinery, boilers, pressure vessels and piping systems.

1.1.2 Where required by the relevant Rules dealing with design and construction, castings are to be manufactured and tested in accordance with *Ch 1 General Requirements* and *Ch 7, 2 Grey iron castings*, together with the requirements given in this Section and either *Ch 7, 2 Grey iron castings* for grey iron castings, *Ch 7, 3 Spheroidal or nodular graphite iron castings* for spheroidal graphite iron castings or *Ch 7, 4 Compacted or vermicular graphite iron castings* for compacted graphite iron castings. Castings for crankshafts are additionally to comply with the requirements detailed in *Ch 7, 5 Iron castings for crankshafts*.

1.1.3 As an alternative to *Ch 7, 1.1 Scope 1.1.2*, castings which comply with National or proprietary specifications may be accepted, provided that these specifications give reasonable equivalence to the requirements of this Chapter or alternatively are approved for a specific application. Generally, survey and certification are to be carried out in accordance with the requirements of *Ch 1 General Requirements*.

1.1.4 Where small castings are produced in large quantities, or where castings of the same type are produced in regular quantities, alternative survey procedures, in accordance with *Ch 1, 2.2 LR Approval – General*, may be adopted subject to approval by Lloyd's Register (hereinafter referred as 'LR').

1.2 Manufacture

1.2.1 Castings as designated in *Ch 7, 1.1 Scope 1.1.2* are to be made at foundries approved by LR.

1.2.2 Suitable mechanical methods are to be employed for the removal of surplus material from castings. Thermal cutting processes are not acceptable, except as a preliminary operation to mechanical methods.

1.3 Quality of castings

1.3.1 Castings are to be free from surface or internal defects which would be prejudicial to their proper application in service. The surface finish is to be in accordance with good practice and any specific requirements of the approved plan.

1.4 Chemical composition

1.4.1 The chemical composition of the iron used is left to the discretion of the manufacturer, who is to ensure that it is suitable to obtain the mechanical properties specified for the castings.

1.5 Heat treatment

1.5.1 Except as required by *Ch 7, 1.5 Heat treatment 1.5.2*, castings may be supplied in either the as cast or heat treated condition.

1.5.2 For some applications, such as elevated temperature service, or where dimensional stability is important, castings may require to be given a suitable tempering or stress relieving heat treatment. This is to be carried out after any refining heat treatment and before machining.

1.5.3 Where it is proposed to carry out local hardening of the surface of a casting, full details of the proposed procedure are to be submitted for approval.

1.6 Test material

1.6.1 At least one test sample is to be provided for each casting or batch of castings. For large castings, where more than one ladle of metal is used, one test sample is to be provided, from each ladle used.

1.6.2 A batch testing procedure may be adopted for castings with a fettled mass of 1 tonne or less. All castings in a batch are to be of similar type and dimensions, and cast from the same ladle of metal. One test sample is to be provided for each multiple of two tonnes of fettled castings in the batch.

1.6.3 Where separately cast test samples are used, they are to be cast in moulds made from the same type of material as used for the castings and are not to be stripped from the moulds until the temperature is below 500°C.

1.6.4 All test samples are to be suitably marked to identify them with the castings which they represent.

1.6.5 Where castings are supplied in the heat treated condition, the test samples are to be heat treated together with the castings which they represent. For cast-on test samples, the sample is not to be separated from the casting until after heat treatment.

1.7 Mechanical tests

1.7.1 One tensile specimen is to be prepared from each test sample. The dimensions of the test specimens and the testing procedures used are to be in accordance with *Ch 2 Testing Procedures for Metallic Materials*.

1.7.2 The results of all tensile tests are to comply with the requirements given in *Ch 7, 2 Grey iron castings*, *Ch 7, 3 Spheroidal or nodular graphite iron castings*, *Ch 7, 4 Compacted or vermicular graphite iron castings*or *Ch 7, 5 Iron castings for crankshafts*, as appropriate.

1.7.3 In the case of castings supplied in the as cast condition which initially do not meet the requirements of *Ch 7, 1.7 Mechanical tests 1.7.2*, the manufacturer, by agreement with the purchaser, has the right to heat treat the castings, together with the representative test samples, and re-submit them for acceptance.

1.7.4 In the case of a batch of castings supplied in the heat treated condition which initially do not meet the requirements of *Ch 7, 1.7 Mechanical tests 1.7.2*, the manufacturer has the right to re-heat treat the batch together with the representative test samples, and re-submit the castings for acceptance. The number of reheat treatments and retestings will be restricted to two.

1.8 Visual and non-destructive examination

1.8.1 All castings are to be cleaned and adequately prepared for examination. The surfaces are not to be hammered, peened or treated in any way which may obscure defects.

1.8.2 The accuracy and verification of dimensions are the responsibility of the manufacturer, unless otherwise agreed.

1.8.3 All castings are to be presented to the Surveyor for visual examination and this is to include the examination of internal surfaces where applicable.

1.8.4 The non-destructive examination of castings is not required unless otherwise stated in the approved plan or where there is reason to suspect the soundness of the casting.

1.8.5 In the event of any casting proving defective during subsequent machining or testing it is to be rejected notwithstanding any previous certification.

1.9 Rectification of defective castings

1.9.1 At the discretion of the Surveyor, small surface blemishes may be removed by local grinding.

1.9.2 Subject to the prior approval of the Surveyor, castings containing local porosity may be rectified by vacuum impregnation with a suitable plastic filler, provided that the extent of the porosity is such that it does not adversely affect the strength of the casting.

1.9.3 Repairs by welding are not permitted on grey cast iron castings or compacted graphite iron castings and generally not permitted for spheroidal or nodular graphite iron castings, but may be considered in special circumstances for spheroidal or nodular graphite iron castings. In such cases, full details of the proposed repair procedure are to be submitted for approval prior to the commencement of the proposed rectification.

1.10 Pressure testing

1.10.1 When required by the relevant Rules, castings are to be pressure tested before final acceptance. These tests are to be carried out in the presence and to the satisfaction of the Surveyor.

1.11 Identification of castings

1.11.1 The manufacturer is to adopt a system of identification which will enable all finished castings to be traced to the original cast, and the Surveyor is to be given full facilities for tracing the castings when required.

1.11.2 Before acceptance, all castings which have been tested and inspected with satisfactory results are to be clearly marked by the manufacturer with the following particulars:

(a) Type and grade of cast iron.
(b) Identification number, cast number or other marking which will enable the full history of the casting to be traced.
(c) Manufacturer's name or trade mark.
(d) LR or Lloyd's Register and the abbreviated name of LR's local office.
(e) Personal stamp of Surveyor responsible for inspection.
(f) Test pressure, where applicable.
(g) Date of final inspection.

1.11.3 Where small castings are manufactured in large numbers, modified arrangements for identification may be specially agreed with the Surveyor.

1.12 Certification of materials

1.12.1 A LR certificate is to be issued, *see Ch 1, 3.1 General*.

1.12.2 The manufacturer is to provide the Surveyor with a written statement giving the following particulars for each casting or batch of castings which has been accepted:

(a) Purchaser's name and order number.
(b) Description of castings and quality of cast iron.
(c) Identification number.
(d) General details of heat treatment, where applicable.
(e) Results of mechanical tests.
(f) Test pressure, where applicable.
(g) When specially required, the chemical analysis of ladle samples.

1.12.3 Where applicable, the manufacturer is to provide a signed statement regarding non-destructive testing as required by *Ch 7, 1.8 Visual and non-destructive examination*, together with a statement and/or a sketch detailing the extent and position of all weld repairs made to each casting as required by *Ch 7, 1.9 Rectification of defective castings*.

■ *Section 2*
Grey iron castings

2.1 Scope

2.1.1 This Section gives the specific requirements for grey cast iron castings.

2.2 Test material

2.2.1 Separately cast test samples in the form of cylindrical bars, 30 mm diameter and of a suitable length, are to be used unless otherwise agreed by LR. Test samples of other dimensions may be specially required for some components as may cast-on samples. In these circumstances, the tensile strength requirements are to be agreed.

2.2.2 When two or more test samples are cast simultaneously in a single mould, the bars are to be at least 50 mm apart.

2.2.3 Test samples may be cast integrally when a casting is both more than 20 mm thick and its mass exceeds 200 kg, subject to agreement between the manufacturer and the purchaser. The type and location of the samples are to be such as to provide approximately the same cooling conditions as for the casting it represents and are also subject to agreement.

2.2.4 For continuous melting of the same grade of cast iron in large tonnages the mass of a batch may be taken as the output of two hours of pouring.

2.2.5 Where *Ch 7, 2.2 Test material 2.2.4* applies and production is carefully monitored by systematic checking of the melting process by, for example, chill testing, chemical analysis or thermal analysis, test samples may be taken at longer intervals as agreed by the Surveyor.

2.3 Mechanical tests

2.3.1 Only the tensile strength is to be determined, and the results obtained from tests are to comply with the minimum value specified for the castings being supplied. Except for crankshaft castings (*see Ch 7, 5 Iron castings for crankshafts*), the specified tensile strength is to be not less than 200 N/mm^2 subject to any additional requirements of the relevant Rules. The fractured surfaces of all tensile test specimens are to be granular and entirely grey in appearance.

■ *Section 3*
Spheroidal or nodular graphite iron castings

3.1 Scope

3.1.1 This Section gives the specific requirements for spheroidal or nodular graphite iron castings.

3.1.2 These requirements are generally applicable to castings intended for use at ambient temperatures. Additional requirements will be necessary when the castings are intended for service at either low or elevated temperatures. Impact test requirements are given for low temperature service in *Ch 7, 3.4 Mechanical tests 3.4.2*.

3.2 Heat treatment

3.2.1 The special qualities with 350 N/mm^2 and 400 N/mm^2 nominal tensile strength and impact test are to undergo a ferritising heat treatment, *see Ch 7, 3.4 Mechanical tests 3.4.2*.

3.3 Test material

3.3.1 The test samples are to be as detailed in Figs. *Table 7.3.1 Type A (U-type) test samples*, *Table 7.3.2 Type B (Double U-type) test samples* or *Table 7.3.3 Type C (Y-type) test samples*. The dimensions of the test specimens and testing procedures used are to be in accordance with *Ch 2 Testing Procedures for Metallic Materials*. Test samples of other dimensions may be specially required for some castings and these are to be agreed with the Surveyor.

Table 7.3.1 Type A (U-type) test samples

Dimension	Standard sample, mm	Alternative samples when specially required, mm		
u	25	12	50	75
v	55	40	90	125
x	40	30	60	65
y	100	80	150	165

Z	To suit testing machine
R_s	Approximately 5

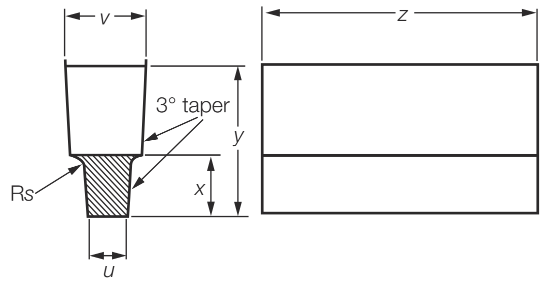


Table 7.3.2 Type B (Double U-type) test samples

Dimension	Standard sample, mm
u	25
v	90
x	40
y	100
Z	To suit testing machine
R_s	Approximately 5

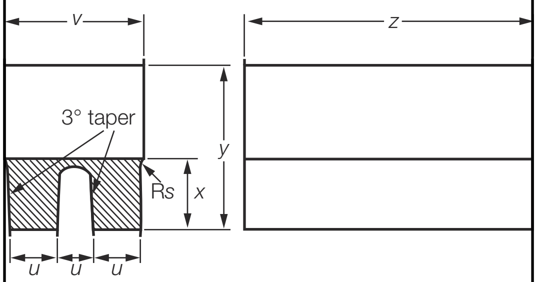
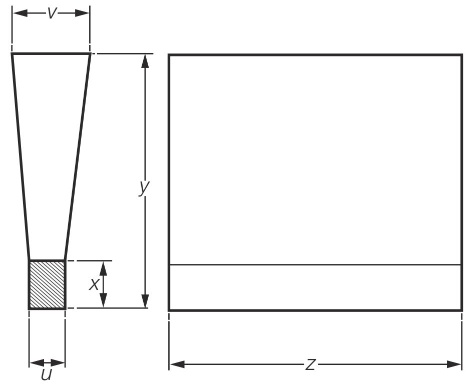


Table 7.3.3 Type C (Y-type) test samples

Dimension	Standard sample, mm	Alternative samples when specially required, mm		
u	25	12	50	75
v	55	40	100	125
x	40	25	50	65
y	140	135	150	175
Z	To suit testing machine			

Minimum thickness of mould surrounding test sample	40	40	80	80



3.3.2 The test samples may be either gated to the casting or separately cast.

3.3.3 Where separately cast test samples are used, they are to be taken towards the end of pouring of the castings.

3.4 Mechanical tests

3.4.1 The tensile strength and elongation are to be determined and are to comply with the requirements of *Table 7.3.4 Mechanical properties for acceptance purposes: spheroidal or nodular graphite iron castings*. Minimum values for the 0,2 per cent proof stress are also included in this Table but are to be determined only if included in the specification. Typical ranges of hardness values are also given in *Table 7.3.4 Mechanical properties for acceptance purposes: spheroidal or nodular graphite iron castings* and are intended for information purposes.

3.4.2 Impact tests may be required for some applications in which case the selection of the grade is to be confined to those listed in *Table 7.3.5 Mechanical properties: special qualities*. These castings are to be given a ferritising heat treatment. The mechanical test results are to comply with *Table 7.3.5 Mechanical properties: special qualities*.

3.4.3 Castings may be supplied to any specified minimum tensile strength selected within the general limits detailed in *Table 7.3.4 Mechanical properties for acceptance purposes: spheroidal or nodular graphite iron castings* and *Table 7.3.5 Mechanical properties: special qualities* but subject to any additional requirements of the relevant Rules.

Table 7.3.4 Mechanical properties for acceptance purposes: spheroidal or nodular graphite iron castings

Specified minimum tensile strength N/mm^2	0,2% proof stress (*see* Note) N/mm^2 minimum	Elongation on $5{,}65\sqrt{S_0}$ % minimum	Typical hardness value HB (*see Ch 7, 3.4 Mechanical tests 3.4.1*)	Typical structure of matrix (*see Ch 7, 3.5 Metallographic examination 3.5.2*)
370	230	17	120 – 180	Ferrite
400	250	12	140 – 200	Ferrite
500	320	7	170 – 240	Ferrite/pearlite
600	370	3	190 – 270	Pearlite/ferrite
700	420	2	230 – 300	Pearlite
800	480	2	250 – 350	Pearlite or tempered structure
Note Proof stresses need only be determined if specifically requested.				

Table 7.3.5 Mechanical properties: special qualities

Specified minimum tensile strength N/mm^2	0,2% proof stress minimum (*See* Note 1) N/mm^2	Elongation on 5,65 $\sqrt{S_0}$ minimum% (*See* Note 2)	Typical hardness value	Charpy V-notch impact tests	
				Test temperature °C (*See* Note 3)	Average energy J minimum (*See* Note 4)
350	220	22	110 – 170	20 –40	17 (14) 12 (10)
400	250	18	140 – 200	20 –20	14 (11) 12 (10)

Note 1. Proof stresses need only be determined if specifically requested.

Note 2. In the case of integrally cast samples, the acceptable elongation may be taken as 2 percentage points less.

Note 3. Tests need only be made at either of the temperatures listed, as appropriate.

Note 4. The average value measured on three Charpy V-notch specimens. One of the three values may be below the specified minimum average value, but not less than the value shown in brackets.

Note 5. Typical structure of the matrix is ferrite.

3.5 Metallographic examination

3.5.1 Samples for metallographic examination are to be prepared for spheroidal or nodular graphite iron castings. These samples are to be representative of each ladle used and may conveniently be taken from the tensile test specimens. Alternative arrangements for the provision of these samples may, however, be adopted subject to the concurrence of the Surveyor. They are, however, to be taken towards the end of the pour.

3.5.2 Examination of the samples is to show that at least 90 per cent of the graphite is in a dispersed spheroidal or nodular form. Details of typical matrix structures are given in *Table 7.3.4 Mechanical properties for acceptance purposes: spheroidal or nodular graphite iron castings* and are intended for information purposes.

■ *Section 4*
Compacted or vermicular graphite iron castings

4.1 Scope

4.1.1 This Section gives the specific requirements for compacted or vermicular graphite iron castings.

4.1.2 These requirements are generally applicable to castings intended for use at ambient temperatures.

4.2 Heat treatment

4.2.1 Where castings do not meet the specified mechanical property requirements in the as-cast condition, a corrective heat treatment may be carried out. This is to be restricted to a single heat treatment and the test coupons must be heat treated with the castings.

4.3 Test material

4.3.1 The test samples are to be as detailed in *Table 7.3.1 Type A (U-type) test samples*, *Table 7.3.2 Type B (Double U-type) test samples* or *Table 7.3.3 Type C (Y-type) test samples*. The dimensions of the test specimens and testing procedures used are to be in accordance with *Ch 2 Testing Procedures for Metallic Materials*. Test samples of other dimensions may be specially agreed with the Surveyor.

4.3.2 The test samples may be either gated to the casting or separately cast.

4.3.3 Where separately cast test samples are used, they are to be taken towards the end of pouring of the castings.

4.4 Mechanical tests

4.4.1 The tensile strength and elongation are to be determined and are to comply with the requirements of *Table 7.4.1 Mechanical properties for acceptance purposes: compacted or vermicular graphite iron castings*. Minimum values for the 0,2 per cent proof stress are also included in this Table but are to be determined only if included in the specification. Typical ranges of hardness values are also given in *Table 7.4.1 Mechanical properties for acceptance purposes: compacted or vermicular graphite iron castings* and are intended for information purposes.

4.4.2 Castings may be supplied to any specified minimum tensile strength grade.

Table 7.4.1 Mechanical properties for acceptance purposes: compacted or vermicular graphite iron castings

Specified minimum tensile strength N/mm²	0,2% proof stress (see Note) N/mm² minimum	Elongation on 5,65 √ So % minimum	Typical hardness value HB (*see Ch 7, 4.4 Mechanical tests 4.4.1*)	Typical structure of matrix (*see Ch 7, 4.5 Metallographic examination 4.5.2*)
300	210	2	140 – 210	Ferrite
350	245	1,5	160 – 220	Ferrite/pearlite
400	280	1	180 – 240	Pearlite/ferrite
450	315	1	200 – 250	Pearlite
500	350	0,5	220 – 260	Fully pearlitic
Note Proof stresses need only be determined if specifically requested.				

4.5 Metallographic examination

4.5.1 Samples for metallographic examination are to be prepared for compacted or vermicular graphite iron castings. These samples are to be representative of each ladle used and may conveniently be taken from the tensile test specimens. Alternative arrangements for the provision of these samples may, however, be adopted subject to the concurrence of the Surveyor. They are, however, to be taken towards the end of the pour.

4.5.2 Examination of the samples is to show that at least 80 per cent of the graphite is in a dispersed, compacted or vermicular form. The remaining 20 per cent of the graphite may be in spheroidal forms. Details of typical matrix structures are given in *Table 7.4.1 Mechanical properties for acceptance purposes: compacted or vermicular graphite iron castings* and are intended for information purposes.

■ *Section 5* Iron castings for crankshafts

5.1 Scope

5.1.1 This Section gives additional requirements for cast iron crankshafts intended for engines and compressors. For both of these applications, details of the proposed specification are to be submitted for approval.

5.1.2 Crankshaft castings in grey iron and compacted graphite iron are acceptable only for compressors, and the specified minimum tensile strength is to be not less than 300 N/mm^2.

5.1.3 For crankshaft castings in spheroidal or nodular graphite iron, the specified minimum tensile strength is to be not less than 370 N/mm^2.

5.2 Manufacture

5.2.1 Details of the method of manufacture, including the arrangements proposed for the provision of test material, are to be submitted for approval.

5.2.2 Tests to demonstrate the soundness of prototype castings and the mechanical properties at important locations will be required.

5.3 Heat treatment

5.3.1 In general, crankshaft castings other than those which are fully annealed, normalised or oil quenched and tempered, are to receive a suitable stress relief heat treatment before machining.

5.3.2 Where it is proposed to harden the surfaces of machined pins and/or journals of cast iron crankshafts, details of the process are to be submitted for approval. Before such a process is applied to a crankshaft it is to be demonstrated by procedure tests, and to the satisfaction of the Surveyor, that the process is suitably controlled and does not impair the strength or soundness of the material.

5.4 Test material

5.4.1 Unless otherwise approved, the dimensions of the test samples are to be such as to ensure that they have mechanical properties representative of those of the average section of the crankshaft casting.

5.4.2 For large crankshaft castings, the test samples are to be cast integral with, or gated from, each casting.

5.4.3 The batch testing procedure detailed in *Ch 7, 1.6 Test material 1.6.2* may be adopted only where small and identical crankshaft castings are produced in quantity. Generally, the fettled mass of each casting in a batch is not to exceed 100 kg, and in addition to tensile tests, the hardness of each casting is to be determined. For this purpose, a small flat is to be ground on each crankshaft, and Brinell hardness tests are to be carried out. The results obtained from these tests are to comply with the approved specification.

5.5 Non-destructive examination

5.5.1 Cast crankshafts are to be subjected to a full magnetic particle or dye penetrant examination after final machining and completion of any surface hardening operations.

5.5.2 Particular attention is to be given to the testing of the pins, journals and associated fillet radii.

5.5.3 Cracks and crack-like defects are not acceptable. Fillet radii are to be free from any indications.

5.5.4 Each casting is to be examined by ultrasonic testing, and the extent of examination and defect acceptance criteria, using the DGS (Distance Gain Size) technique, are to be as shown in *Figure 7.5.1 Ultrasonic examination acceptance levels*. Alternative ultrasonic procedures may be submitted for review.

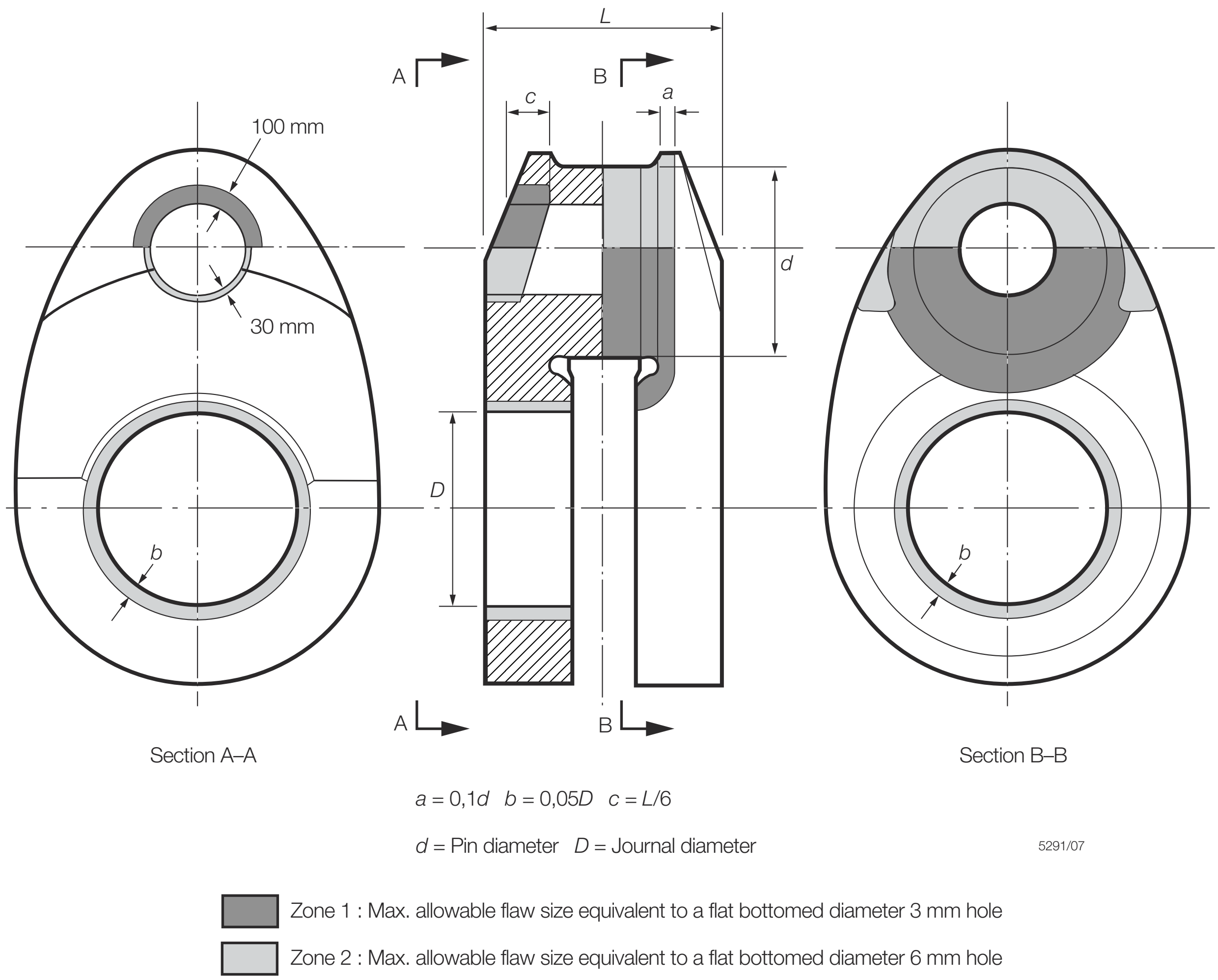


Figure 7.5.1 Ultrasonic examination acceptance levels

5.6 Rectification of defective castings

5.6.1 Cast iron crankshafts are not to be repaired by welding, and blemishes are not to be plugged with a filler.

5.7 Certification of materials

5.7.1 The chemical composition of ladle samples is to be given in addition to the other particulars detailed in *Ch 7, 1.12 Certification of materials 1.12.2*.

■ *Section 1*
Plates, bars and sections

1.1 Scope

1.1.1 This Section makes provision for aluminium alloy plates, bars and sections intended for use in the construction of ships and other marine structures and for cryogenic applications.

1.1.2 Except as provided in *Ch 8, 1.1 Scope 1.1.4*, all items are to be manufactured and tested in accordance with the appropriate requirements of *Ch 1 General Requirements* and *Ch 2 Testing Procedures for Metallic Materials* and those detailed in this Section.

1.1.3 The thickness of plates, sections and bars described by these requirements will be in the range between 3 and 50 mm. Plates and sections less than 3,0 mm thick may be manufactured and tested in accordance with the requirements of an acceptable national specification.

1.1.4 Plates less than 3,0 mm thick and sections less than 40 mm × 40 mm × 3,0 mm may be manufactured and tested in accordance with the requirements of an acceptable National specification.

1.1.5 Where the section thickness exceeds 50 mm the requirements will be subject to special consideration.

1.1.6 Materials intended for the construction of cargo tanks or storage for liquefied gases, and for other low temperature applications, are to be manufactured in the 5083 alloy in the annealed condition.

1.1.7 As an alternative to *Ch 8, 1.1 Scope 1.1.2* and *Ch 8, 1.1 Scope 1.1.4*, materials which comply with National or proprietary specifications may be accepted provided that these specifications give reasonable equivalence to the requirements of this Section and are approved for a specific application. Generally, survey and certification are to be carried out in accordance with the requirements of *Ch 1 General Requirements*.

1.2 Manufacture

1.2.1 Aluminium alloys are to be manufactured at works approved by Lloyd's Register (hereinafter referred as 'LR').

1.2.2 The alloys may be cast either in ingot moulds or by an approved continuous casting process. Plates are to be formed by rolling and may be hot or cold finished. Bars and sections may be formed by extrusion, rolling or drawing.

1.2.3 All melts are to be suitably degassed prior to casting such that the aim hydrogen content is less than 0,2 ml per 100 g.

1.3 Quality of materials

1.3.1 Materials are to be free from surface or internal defects of such a nature as would be harmful in service.

1.3.2 The manufacturer is to verify the integrity of pressure welds of closed extrusion profiles in accordance with *Ch 8, 1.10 Pressure weld tests*.

1.4 Dimensional tolerances

1.4.1 Underthickness tolerances for rolled products for marine construction are given in *Table 8.1.1 Underthickness tolerances for rolled products for marine construction*.

Table 8.1.1 Underthickness tolerances for rolled products for marine construction

Nominal thickness range, mm	Underthickness tolerance for nominal width range, mm		
	≤1500	>1500 ≤2000	>2000 ≤3500
≥3,0 <4,0	0,10	0,15	0,15
≥4,0 <8,0	0,20	0,20	0,25
≥8,0 <12	0,25	0,25	0,25
≥12 <20	0,35	0,40	0,50
≥20 <50	0,45	0,50	0,65

1.4.2 Underthickness tolerances for extruded products are to comply with an acceptable National or International Standard.

1.4.3 There are to be no underthickness tolerances for materials for application in cryogenic process pressure vessels.

1.4.4 Dimensional tolerances other than permitted underthicknesses are to comply with an acceptable National or International Standard.

1.4.5 Verification of dimensions is the responsibility of the manufacturer. Acceptance by Surveyors of material which is later found to be defective does not absolve the manufacturer from this responsibility.

1.5 Chemical composition

1.5.1 Samples for chemical analysis are to be taken representative of each cast, or the equivalent where a continuous melting process is involved.

1.5.2 The chemical composition of these samples is to comply with the requirements of *Table 8.1.2 Chemical composition, percentage*.

Table 8.1.2 Chemical composition, percentage

Element	5083	5383	5059	5086	5754	5456	6005–A (*see* Note 1)	6061 (*see* Note 1)	6082
Copper	0,10 max.	0,20 max.	0,25 max.	0,10 max.	0,10 max.	0,10 max.	0,30 max.	0,15—0,40	0,10 max.
Magnesium	4,0—4,9	4,0—5,2	5,0—6,0	3,5—4,5	2,6—3,6	4,7—5,5	0,40—0,70	0,80—1,20	0,60—1,20
Silicon	0,40 max.	0,25 max.	0,45 max.	0,40 max.	0,40 max.	0,25 max.	0,50—0,90	0,40—0,80	0,70—1,30
Iron	0,40 max.	0,25 max.	0,50 max.	0,50 max.	0,40 max.	0,40 max	0,35 max.	0,70 max.	0,50 max.
Manganese	0,40—1,00	0,7—1,0	0,6—1,2	0,20—0,70	0,50 max. (*see* Note 2)	0,50—1,00	0,50 max. (*see* Note 3)	0,15 max.	0,40—1,00
Zinc	0,25 max.	0,40 max.	0,40—0,90	0,25 max.	0,20 max.	0,25 max.	0,20 max.	0,25 max.	0,20 max.
Chromium	0,05—0,25	0,25 max.	0,25 max.	0,05—0,25	0,30 max. (*see* Note 2)	0,05—0,20	0,30 max. (*see* Note 3)	0,04—0,35	0,25 max.
Titanium	0,15 max	0,15 max.	0,20 max.	0,15 max.	0,15 max.	0,20 max.	0,10 max.	0,15 max.	0,10 max.
Zirconium		0,20 max.	0,05—0,25						
Other elements:									

each	0,05 max.	0,05 max.	0,05 max.	0,05 max.	0,05 max.	0,05 max.	0,05 max.	0,05 max.	0,05 max.
total	0,15 max.	0,15 max.	0,15 max.	0,15 max.	0,15 max.	0,15 max.	0,15 max.	0,15 max.	0,15 max.

Note 1. These alloys are not normally acceptable for application in direct contact with sea-water.

Note 2. Mn + Cr = 0,10 min., 0,60 max.

Note 3. Mn + Cr = 0,12 min., 0,50 max.

Table 8.1.3 Minimum mechanical properties for acceptance purposes of selected rolled aluminium alloy products

Alloy and temper condition, *see* Note 3	Thickness, t, mm	0,2% proof stress R_p, N/mm^2	Tensile strength R_m N/mm^2	Elongation 4d, %	Elongation on $5,65\sqrt{S_0}$ 5d,%
5083-O	$3 \le t \le 50$ (*see* Note 2)	125	275–350	16	14
5083-H111	$3 \le t \le 50$	125	275-350	16	14
5083-H112	$3 \le t \le 50$	125	275	12	10
5083-H116	$3 \le t \le 50$	215	305	10	10
5083-H321	$3 \le t \le 50$	215–295	305–380	12	10
5086-O	$3 \le t \le 50$	100	240–305	16	14
5086-H111	$3 \le t \le 50$	100	240–305	16	14
5086-H112	$3 \le t \le 12{,}5$	125	250	8	–
	$12{,}5 < t \le 50$	105	240	–	9
5086-H116	$3 \le t \le 50$	195	275	10 (*see* Note 1)	9
5059-O	$3 \le t \le 50$	160	330	24	24
5059-H111	$3 \le t \le 50$	160	330	24	24
5059-H116	$3 \le t \le 20$	270	370	10	10
	$20 < t \le 50$	260	360	10	10
5059-H321	$3 \le t \le 20$	270	370	10	10
	$20 < t \le 50$	260	360	10	10
5383-O	$3 \le t \le 50$	145	290	17	17
5383-H111	$3 \le t \le 50$	145	290	17	17
5754-H111	$3 \le t \le 50$	80	190–240	18	17
5383-H116	$3 \le t \le 50$	220	305	10	10
5383-H321	$3 \le t \le 50$	220	305	10	10
5456-O	$3 \le t \le 6{,}3$	130–205	290–365	16	–
	$6{,}3 \le t \le 50$	125–205	285–360	16	14
	$3 \le t \le 30$	230	315	10	10
5456-H116	$30 < t \le 40$	215	305	–	10
	$40 < t \le 50$	200	285	–	10
	$3 \le t \le 12{,}5$	230–315	315–405	12	–

5456-H321	12,5 ≤ t ≤ 40	215–305	305–385	–	10
	40 ≤ t ≤ 50	200–295	285–370	–	10
5754-O	3 ≤ t ≤ 50	80	190–240	18	17

Note 1. 8% for thickness up to and including 6,3 mm.

Note 2. For application to liquefied natural gas carriers or liquefied natural gas tankers where thicknesses are in excess of 50 mm, the mechanical properties given in this table are, in general, to be complied with.

Note 3. The mechanical properties for the O and H111 tempers are the same for all alloys shown in this Table. However, they are separated in this Table as they are made using different manufacturing processes

1.6 Heat treatment

1.6.1 The Aluminium 5000 series alloys, capable of being strain hardened, are to be supplied in any of the following temper conditions:

O	annealed
H111	annealed with slight strain hardening
H112	strain hardened from working at elevated temperatures
H116	strain hardened and with specified resistance to exfoliation corrosion for alloys where the magnesium content is 4 per cent or more
H321	strain hardened and stabilised.

1.6.2 The H116 temper is specially developed for use in a marine environment.

1.6.3 The Aluminium 6000 series alloys, capable of being age hardened, are to be supplied in either of the following temper conditions:

T5	hot worked and artificially aged.
T6	solution treated and artificially aged.

1.7 Test material

1.7.1 Materials of the same product form, (i.e. plates, sections or bars) and thickness and from a single cast or equivalent, are to be presented for test in batches of not more than 2 tonnes, with the exceptions of those given in *Ch 8, 1.7 Test material 1.7.2*, *Ch 8, 1.7 Test material 1.7.3* and *Ch 8, 1.7 Test material 1.7.4*.

1.7.2 For single plates or coils weighing more than 2 tonnes, only one tensile specimen per plate or coil is to be taken.

1.7.3 A tensile test specimen is required from each plate to be used in the construction of cargo tanks, secondary barriers and process pressure vessels with design temperatures below -55°C.

1.7.4 Extrusions, bars and sections of less than 1 kg/m in nominal weight are to be tested in batches of 1 tonne. Where the nominal weight is greater than 5 kg/m, one tensile test is to be carried out for every three tonnes produced, or fractions thereof.

1.7.5 If the material is supplied in the heat treated condition, each batch is to be treated together in the same furnace or subjected to the same finishing treatment when a continuous furnace is used.

1.7.6 For plates over 300 mm in width, tensile test specimens are to be cut with their length transverse to the principal direction of rolling. For narrow plates and for sections and bars, the test specimens are to be cut in the longitudinal direction. Longitudinal tensile test specimens are accepted for the strain hardenable 5000 series alloys.

1.7.7 Longitudinal tensile test specimens from a plate are to be taken at $\frac{1}{3}$ width from the longitudinal edge. Longitudinal tensile test specimens taken from extruded sections should be taken in the range from $\frac{1}{3}$ to $\frac{1}{2}$ of the distance from the edge to the centre of the thickest region of the section.

1.8 Mechanical tests

1.8.1 At least one tensile test specimen is to be prepared from each batch of material submitted for acceptance.

1.8.2 Tensile test specimens are to be machined to the dimensions given in *Figure 2.2.3 Test specimen dimensions for plates, strip and sections - I and aluminum alloys* in Chapter 2. Alternatively, machined proportional test specimens of circular cross-section in accordance with *Figure 2.2.2 Test specimen dimensions for forgings and castings - II and aluminum alloys* in Chapter 2 may be used provided that the diameter is not less than 10 mm. Round bars may be tested in full section, or test specimens may be machined in accordance with the dimensions given in *Figure 2.2.2 Test specimen dimensions for forgings and castings - II and aluminum alloys* in Chapter 2.

1.8.3 The results of all tensile tests are to comply with the values given in *Table 8.1.3 Minimum mechanical properties for acceptance purposes of selected rolled aluminium alloy products* and *Table 8.1.4 Minimum mechanical properties for acceptance purposes of selected extruded aluminium alloy products*, as applicable.

Table 8.1.4 Minimum mechanical properties for acceptance purposes of selected extruded aluminium alloy products

Alloy and temper condition, *See* Note 2	Thickness, *t*, mm	0,2% proof stress R_{p}, N/mm^2	Tensile strength R_{m} N/mm^2	Elongation on 4*d*, %	Elongation on $5,65\sqrt{S_0}$ 5*d*, %
5083-O	$3 \le t \le 50$	110	270–350	14	12
5083-H111	$3 \le t \le 50$	165	275	12	10
5083-H112	$3 \le t \le 50$	110	270	12	10
5086-O	$3 \le t \le 50$	95	240–315	14	12
5086-H111	$3 \le t \le 50$	145	250	12	10
5086-H112	$3 \le t \le 50$	95	240	12	10
5059-H112	$3 \le t \le 50$	200	330	10	10
5383-O	$3 \le t \le 50$	145	290	17	17
5383-H111	$3 \le t \le 50$	145	290	17	17
5383-H112	$3 \le t \le 50$	190	310	13	13
6005A-T5	$3 \le t \le 50$	215	260	9	8
6005A-T6	$3 \le t \le 10$	215	260	8	6
	$10 < t \le 50$	200	250	8	6
6061-T6	$3 \le t \le 50$	240	260	10	8
6082-T5	$3 \le t \le 50$	230	270	8	6
6082-T6	$3 \le t \le 5$	250	290	6	–
	$5 < t \le 50$	260	310	10	8

Note 1. The values are applicable for longitudinal and transverse tensile test specimens as well.

Note 2. The mechanical properties for the O and H111 tempers are the same for all alloys shown in this Table. However, they are separated in this Table as they are made using different manufacturing processes.

1.9 Corrosion tests

1.9.1 Rolled 5000 series alloys of type 5083, 5383, 5059, 5456 and 5086 in the H116 and H321 tempers intended for use in marine hull construction or in marine applications with frequent direct contact with seawater are to be corrosion tested with respect to exfoliation and intergranular corrosion resistance.

1.9.2 The manufacturer is to establish the relationship between microstructure and resistance to corrosion when the above alloys are approved. A reference photomicrograph taken at 500x, under the conditions specified in ASTM B928 Section 9.4.1, is to be prepared for each of the alloy-tempers and thickness ranges relevant. The reference photographs are to be taken from

samples which have exhibited no evidence of exfoliation corrosion and a pitting rating of PB or better, when subjected to the test described in ASTM G66 (ASSET).The samples are also to have exhibited resistance to intergranular corrosion at a mass loss no greater than 15 mg/cm^2, when subjected to the test described in ASTM G67 (NAMLT). Upon satisfactory establishment of the relationship between microstructure and resistance to corrosion, the master photomicrographs and the results of the corrosion tests are to be approved by LR. Production practices are not to be changed after approval of the reference micrographs.

1.9.3 For batch acceptance of 5000 series alloys in the H116 and H321 tempers, metallographic examination of one sample selected from mid width at one end of a coil or random sheet or plate is to be carried out. The microstructure of the sample is to be compared to the reference photomicrograph of acceptable material in the presence of the Surveyor. A longitudinal section perpendicular to the rolled surface is to be prepared for metallographic examination, under the conditions specified in ASTM B928 Section 9.6.1. If the microstructure shows evidence of continuous grain boundary network of aluminium-magnesium precipitate in excess of the reference photomicrographs of acceptable material, the batch is either to be rejected or tested for exfoliation corrosion resistance and intergranular corrosion resistance subject to the agreement of the Surveyor. The corrosion tests are to be in accordance with ASTM G66 and G67 or equivalent standards. Acceptance criteria are that the sample shall exhibit no evidence of exfoliation corrosion and a pitting rating of PB or better when test subjected to ASTM G66 (ASSET) test, and the sample is to exhibit resistance to intergranular corrosion at a mass loss no greater than 15 mg/cm^2 when subjected to ASTM G67 (NAMLT) test. If the results from testing satisfy the acceptance criteria stated in *Ch 8, 1.9 Corrosion tests 1.9.2*, the batch is accepted, otherwise it is to be rejected.

1.9.4 As an alternative to metallographic examination, each batch may be tested for exfoliation corrosion resistance and intergranular corrosion resistance, in accordance with ASTM G66 and G67 under the conditions specified in ASTM B298, or equivalent standards. If this alternative is used, then the results of the test must satisfy the acceptance criteria stated in *Ch 8, 1.9 Corrosion tests 1.9.2*.

1.9.5 Tempers that are corrosion tested in accordance with *Ch 8, 1.9 Corrosion tests 1.9.3* are to be marked 'M' after the temper condition, e.g. 5083 H321 M.

1.10 Pressure weld tests

1.10.1 The integrity of pressure welds of closed profile extrusions is to be verified by examination of macrosections or drift expansion tests.

1.10.2 Every closed profile extrusion is to be sampled, except where the closed profile extrusions are equal to or shorter than 6,0 m long, in which case a batch is to comprise of five profiles. Every sample is to be tested at both ends after final heat treatment.

1.10.3 Where verification is by examination of macrosections, no indication of lack of fusion is permitted.

1.10.4 Where verification of fusion at pressure welds of closed profile extrusions is by drift expansion test, testing is to be generally in accordance with *Ch 2, 4.3 Drift expanding tests*. The minimum included angle of the mandrel is to be 60°, and the minimum specimen length, 50 mm. For acceptance, there is to be no failure by a clean split along the weld line.

1.11 Visual and non-destructive examination

1.11.1 Surface inspection and verification of dimensions are the responsibility of the manufacturer, and acceptance by the Surveyors of material later found to be defective shall not absolve the manufacturer from this responsibility.

1.11.2 In general, the non-destructive examination of materials is not required for acceptance purposes. Manufacturers are expected, however, to employ suitable methods of non-destructive examination for the general maintenance of quality standards.

1.11.3 For applications where the non-destructive examination of materials in considered to be necessary, the extent of this examination, together with appropriate acceptance standards, are to be agreed between the purchaser, manufacturer and Surveyor.

1.12 Rectification of defects

1.12.1 Slight surface imperfections may be removed by mechanical means, provided that the prior agreement of the Surveyor is obtained, that the work is carried out to his satisfaction and that the final dimensions are acceptable. The repair of defects by welding is not allowed.

1.13 Identification

1.13.1 The manufacturer is to adopt a system of identification which will ensure that all finished material in a batch presented for test is of the same nominal chemical composition.

1.13.2 Products are to be clearly marked by the manufacturer in accordance with the requirements of *Ch 1 General Requirements*. The following details are to be shown on all materials which have been accepted:

(a) Manufacturer's name or trade mark.
(b) Alloy grade and temper condition.
(c) Identification mark which will enable the full history of the item to be traced.
(d) The stamp of the LR brand.

1.14 Certification of materials

1.14.1 A manufacturer’s certificate validated by LR is to be issued, *see Ch 1, 3.1 General*.

1.14.2 Each test certificate is to include the following particulars:

(a) Purchaser's name and order number.
(b) Contract number.
(c) Address to which material is to be despatched.
(d) Description and dimensions.
(e) Alloy grade and temper condition.
(f) Identification mark which will enable the full history of the item to be traced.
(g) Chemical composition.
(h) Mechanical test results (not required on shipping statement).
(i) Details of temper condition and heat treatment, where applicable.
(j) Corrosion test results (as applicable).

1.14.3 Where the alloy is not produced at the works at which it is wrought, a certificate is to be supplied by the manufacturer of the alloy stating the cast number and chemical composition. The works at which the alloy was produced must be approved by LR.

■ *Section 2*
Aluminium alloy rivets

2.1 Scope

2.1.1 Provision is made in this Section for aluminium alloy rivets intended for use in the construction of marine structures.

2.1.2 They are to be manufactured and tested in accordance with the appropriate requirements of *Ch 8, 1 Plates, bars and sections* and those detailed in this Section.

2.2 Chemical composition

2.2.1 The chemical composition of bars used for the manufacture of rivets is to comply with the requirements of *Table 8.2.1 Chemical composition, percentage*.

Table 8.2.1 Chemical composition, percentage

Element	5154A	6082
Copper	0,10 max.	0,10 max.
Magnesium	3,1 – 3,9	0,6 – 1,2
Silicon	0,50 max.	0,7 – 1,3
Iron	0,50 max.	0,50 max.
Manganese	0,1 – 0,5	0,4 – 1,0
Zinc	0,20 max.	0,20 max.
Chromium	0,25 max.	0,25 max.

Titanium		0,20 max.	0,10 max.
Other elements:	each	0,05 max.	0,05 max.
	total	0,15 max.	0,15 max.
Aluminium		Remainder	Remainder

2.3 Heat treatment

2.3.1 Rivets are to be supplied in the following condition:

5154A - annealed

6082 - solution treated.

2.4 Test material

2.4.1 Bars intended for the manufacture of rivets are to be presented for test in batches of not more than 250 kg. The material in each batch is to be the same diameter and nominal chemical composition.

2.4.2 At least one test sample is to be selected from each batch and, prior to testing, is to be heat treated in full cross-section and in a manner simulating the heat treatment applied to the finished rivets.

2.5 Mechanical tests

2.5.1 At least one tensile and one dump test specimen are to be prepared from each test sample.

2.5.2 The tensile test specimen may be either a suitable length of bar tested in full cross-section or a specimen machined to the dimensions given in *Figure 2.2.2 Test specimen dimensions for forgings and castings - II and aluminum alloys* in Chapter 2.

2.5.3 The dump test specimen is to consist of a section cut from the bar with the ends perpendicular to the axis. The length of this section is to be equal to the diameter of the bar.

2.5.4 The results of tensile tests are to comply with the appropriate requirements of *Table 8.2.2 Mechanical properties for acceptance purposes*.

Table 8.2.2 Mechanical properties for acceptance purposes

Mechanical properties	5154A	6082
0,2% proof stress N/mm^2 min.	90	120
Tensile strength N/mm^2 min.	220	190
Elongation on 5,65 $\sqrt{S_0}$ % min.	18	16

2.5.5 The dump test is to be carried out at ambient temperature and is to consist of compressing the specimen until the diameter is increased to 1,6 times the original diameter. After compression, the specimen is to be free from cracks.

2.6 Tests from manufactured rivets

2.6.1 At least three samples are to be selected from each consignment of manufactured rivets. Dump tests as detailed in *Ch 8, 2.5 Mechanical tests* are to be carried out on each sample.

2.7 Identification

2.7.1 Each package of manufactured rivets is to be identified with attached labels giving the following details:

(a) Manufacturer's name or trade mark.
(b) Alloy grade.
(c) Rivet size.

2.8 Certification of materials

2.8.1 A manufacturer’s certificate is to be issued (*see Ch 1, 3.1 General*) and for each consignment of manufactured rivets is to include the following particulars:

(a) Purchaser's name and order number.
(b) Description and dimensions.
(c) Specification.

Section 3
Aluminium alloy castings

3.1 Scope

3.1.1 Provision is made in this Section for aluminium alloy castings intended for use in the construction of ships, ships for liquid chemicals and other marine structures and liquefied gas piping systems where the design temperature is not lower than minus 165°C. These materials should not be used for piping systems outside cargo tanks except for short lengths of pipes attached to the cargo tanks in which case fire-resisting insulation should be provided.

3.1.2 Castings are to be manufactured and tested in accordance with Chapters *Ch 1 General Requirements* and *Ch 2 Testing Procedures for Metallic Materials* and also with the requirements of this Section.

3.1.3 As an alternative to *Ch 8, 3.1 Scope 3.1.2*, castings which comply with National or proprietary specifications may be accepted provided that these specifications give reasonable equivalence to the requirements of this Section or are approved for a specific application. Generally, survey and certification are to be carried out in accordance with the requirements of *Ch 1 General Requirements*.

3.2 Manufacture

3.2.1 Castings are to be manufactured at foundries approved by LR.

3.3 Quality of castings

3.3.1 All castings are to be free from surface or internal defects which would be prejudicial to their proper application in service.

3.4 Chemical composition

3.4.1 The chemical composition of a sample from each cast is to comply with the requirements given in *Table 8.3.1 Chemical composition , percentage*. Suitable grain refining elements may be used at the discretion of the manufacturer. The content of such elements is to be reported in the ladle analysis.

Table 8.3.1 Chemical composition , percentage

Alloy Element		Al–Mg 3	Al–Si 12	Al–Si 10 Mg	Al–Si 7 High purity
Copper		0,1 max	0,1 max.	0,1 max.	0,1 max.
Magnesium		2,5-4,5	0,1 max.	0,15-0,4	0,25-0,45
Silicon		0,5 max.	11,0-13,5	9,0-11,0	6,5-7,5
Iron		0,5 max.	0,7 max.	0,6 max.	0,2 max.
Manganese		0,6 max.	0,5 max.	0,6 max.	0,1 max.
Zinc		0,2 max.	0,1 max.	0,1 max.	0,1 max.
Chromium		0,1 max.	-	-	-
Titanium		0,2 max.	0,2 max.	0,2 max.	0,2 max.
Others	each	0,05 max.	0,05 max.	0,05 max.	0,05 max.
	Total	0,15 max.	0,15 max.	0,15 max.	0,15 max.
Aluminium		Remainder	Remainder	Remainder	Remainder

3.4.2 Where it is proposed to use alloys not specified in *Table 8.3.1 Chemical composition , percentage*, details of the chemical composition, heat treatment and mechanical properties are to be submitted for approval.

3.4.3 When a cast is wholly prepared from ingots for which an analysis is already available, and provided that no significant alloy additions are made during melting, the ingot maker's certified analysis can be accepted subject to occasional checks as required by the Surveyor.

3.5 Heat treatment

3.5.1 Castings are to be supplied in the following conditions:

Grade Al-Mg 3	-	as-manufactured
Grade Al-Si 12	-	as-manufactured
Grade Al-Si 10 Mg	-	as-manufactured or solution heat treated and precipitation hardened
Grade Al-Si 7 Mg	-	solution heat treated and
(high purity)	-	precipitation hardened.

3.6 Mechanical tests

3.6.1 At least one tensile specimen is to be tested from each cast and, where heat treatment is involved, for each heat treatment batch from each cast. Where continuous melting is employed, 500 kg of fettled castings may be regarded as a cast.

3.6.2 The test samples are to be separately cast in moulds made from the same type of material as used for the castings. These moulds should conform to National Standards.

3.6.3 The method and procedures for the identification of the test specimens, and the castings they represent, are to be agreed with the Surveyor. The identification marks are to be maintained during the preparation of test specimens.

3.6.4 Where castings are supplied in the heat treated condition, the test samples are to be heat treated together with the castings which they represent prior to testing.

3.6.5 The results of all tensile tests are to comply with the appropriate requirements given in *Table 8.3.2 Minimum mechanical properties for acceptance purposes of sand-cast and investment cast reference test pieces* and/or *Table 8.3.3 Minimum mechanical properties for acceptance purposes of chill-cast reference test pieces*.

Table 8.3.2 Minimum mechanical properties for acceptance purposes of sand-cast and investment cast reference test pieces

Alloy	Temper (*see* Note)	Tensile strength N/mm^2	Elongation %
Al–Mg 3	M	150	5
Al–Si 12	M	150	3
Al–Si 10 Mg	M	150	2
Al–Si 10 Mg	TF	220	1
Al–Si 7 Mg	TF	230	5
Note M refers to as cast condition.			
Note TF refers to solution heat treated and precipitation hardened condition.			

3.6.6 Where the results of a test do not comply with the requirements, the re-test procedure detailed in *Ch 2, 1.4 Re-testing procedures* is to be applied. Where castings are to be used in the heat treated condition, the re-test sample must have been heat treated together with the castings it represents.

Table 8.3.3 Minimum mechanical properties for acceptance purposes of chill-cast reference test pieces

Alloy	Temper (*see* Note)	Tensile strength N/mm^2	Elongation %
Al–Mg 3	M	150	5
Al–Si 12	M	170	3
Al–Si 10 Mg	M	170	3
Al–Si 10 Mg	TF	240	1,5
Al–Si 7 Mg	TF	250	5

Note M refers to as cast condition.

Note TF refers to solution heat treated and precipitation hardened condition.

3.7 Visual examination

3.7.1 All castings are to be cleaned and adequately prepared for inspection.

3.7.2 The accuracy and verification of dimensions are the responsibility of the manufacturer, unless otherwise agreed.

3.7.3 Before acceptance, all castings are to be presented to the Surveyor for visual examination.

3.8 Rectification of defective castings

3.8.1 At the discretion of the Surveyor, small surface blemishes may be removed by local grinding.

3.8.2 Where appropriate, repair by welding may be accepted at the discretion of the Surveyor. Such repair is to be made in accordance with an approved procedure.

3.9 Pressure testing

3.9.1 Where required by the relevant Rules, castings are to be pressure tested before final acceptance. Unless otherwise agreed, these tests are to be carried out in the presence and to the satisfaction of the Surveyor.

3.10 Identification

3.10.1 The manufacturer is to adopt a system of identification which will enable all finished castings to be traced to the original cast and the Surveyor is to be given full facilities for tracing the casting when required.

3.10.2 All castings which have been tested and inspected with satisfactory results are to be clearly marked with the following details:

(a) Identification number, cast number or other markings which will enable the full history of the casting to be traced.
(b) LR or Lloyd's Register and the abbreviated name of LR's local office.
(c) Personal stamp of the Surveyor responsible for the inspection.
(d) Test pressure where applicable.
(e) Date of final inspection.

3.10.3 Where small castings are manufactured in large numbers, modified arrangements for identification may be specially agreed with the Surveyor.

3.11 Certification of materials

3.11.1 A LR certificate is to be issued (*see Ch 1, 3.1 General*) giving the following particulars for each casting or batch of castings which have been accepted:

(a) Purchaser's name and order number.
(b) Description of castings and alloy type.
(c) Identification number.
(d) Ingot or cast analysis.
(e) General details of heat treatment, where applicable.
(f) Results of mechanical tests.

(g) Test pressure, where applicable.

■ Section 4
Aluminium/steel transition joints

4.1 Scope

4.1.1 Provision is made in this Section for explosion bonded composite aluminium/steel transition joints used for connecting aluminium structures to steel plating.

4.1.2 Each individual application is to be separately approved as required by the relevant Rules dealing with design and construction.

4.2 Manufacture

4.2.1 Transition joints are to be manufactured by an approved producer in accordance with an approved specification which is to include the maximum temperature allowable at the interface during welding.

4.2.2 The aluminium material is to comply with the requirements of *Ch 8, 1 Plates, bars and sections* and the steel is to be of an appropriate grade complying with the requirements of *Ch 3, 2 Normal strength steels for ship and other structural applications*.

4.2.3 Alternative materials which comply with International, National or proprietary specifications may be accepted provided that they give reasonable equivalence to the requirements of *Ch 8, 4.2 Manufacture 4.2.2* or are approved for a specific application.

4.2.4 Intermediate layers between the aluminium and steel may be used, in which case the material of any such layer is to be specified by the manufacturer and is to be recorded in the approval certificate. Any such intermediate layer is then to be used in all production transition joints.

4.3 Visual and non-destructive examination

4.3.1 Each composite plate is to be subjected to 100 per cent visual and ultrasonic examination in accordance with a relevant National Standard to determine the extent of any unbonded areas. Unbonded areas are unacceptable and any such area plus 25 mm of surrounding sound material is to be discarded.

4.4 Mechanical tests

4.4.1 Two shear test specimens and two tensile test specimens are to be taken from each end of each composite plate for tests to be made on the bond strength. One shear and one tensile test specimen from each end are to be tested at ambient temperature after heating to the maximum allowable interface temperature, *see Ch 8, 4.2 Manufacture 4.2.1*; the other two specimens are to be tested without heat treatment.

4.4.2 Shear tests may be made on a specimen as shown in *Figure 8.4.1 Specimen and procedure for shear tests* or an appropriate equivalent. Tensile tests may be made across the interface by welding extension pieces to each surface or by the ram method shown in *Figure 8.4.2 Ram tensile test* or by an appropriate alternative method.

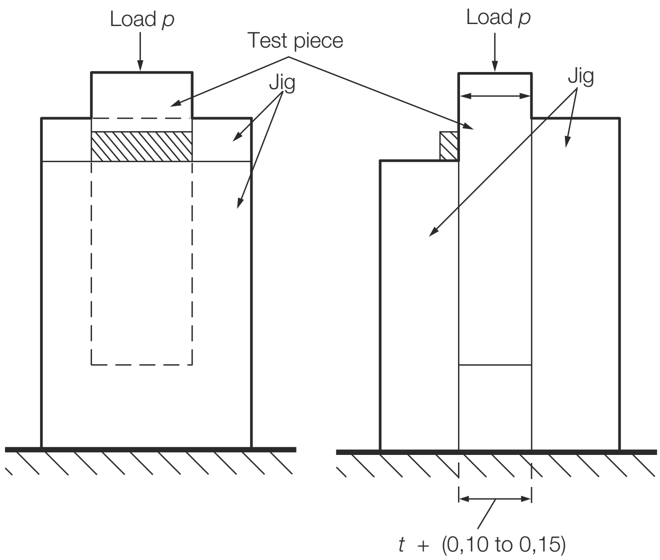


Figure 8.4.1 Specimen and procedure for shear tests

4.4.3 The shear and tensile strengths of all the test specimens are to comply with the requirements of the manufacturing specification.

4.4.4 If either the shear or tensile strength of the bond is less than the specified minimum but not less than 70 per cent of the specified minimum, two additional shear and two tensile test specimens from each end of the composite plate are to be tested and, in addition, bend tests as described in *Ch 8, 4.4 Mechanical tests 4.4.6* and *Table 8.4.1 Bend tests on explosion bonded aluminium/steel composites* are to be made.

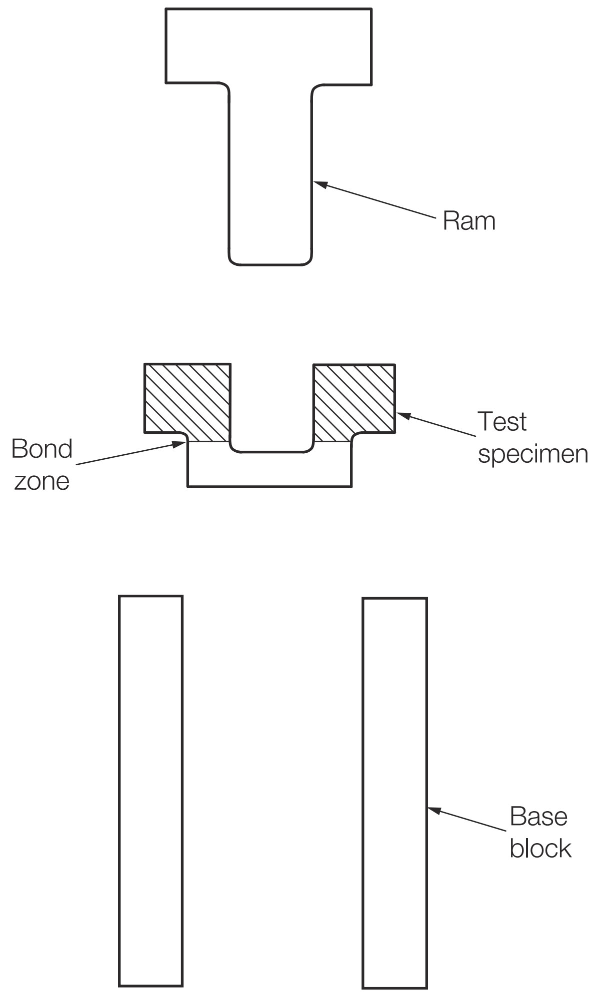


Figure 8.4.2 Ram tensile test

Table 8.4.1 Bend tests on explosion bonded aluminium/steel composites

Type of test	Minimum bend, degrees	Diameter of former
Aluminium in tension	90	3*T*
Steel in tension	90	3*T*
Side bend	90	6*T*
Note *T* is the total thickness of the composite plate.		

4.4.5 If either the shear or tensile strength of the bond is less than 70 per cent of the specified minimum the cause is to be investigated. After evaluation of the results of this investigation, LR will consider the extent of composite plate which is to be rejected.

4.4.6 Bend tests, when required, are to be made under the following conditions, as listed in *Table 8.4.1 Bend tests on explosion bonded aluminium/steel composites*:

(a) The aluminium plate is in tension.
(b) The steel plate is in tension.

(c) A side bend is applied.

4.5 Identification

4.5.1 Each acceptable transition strip is to be clearly marked with the following particulars:

(a) LR or Lloyd's Register and the abbreviated name of LR's local office.
(b) Manufacturer's name or trade mark.
(c) Identification mark for the grade of aluminium.
(d) Identification mark for the grade of steel.

The particulars are to be stamped on the aluminium surface at one end of the strip.

4.6 Certification of materials

4.6.1 A manufacturer’s certificate validated by LR is to be issued (*see Ch 1, 3.1 General*) and as a minimum is to include the following particulars:

(a) Purchaser's name and order number.
(b) The contract number for which the material is intended, if known.
(c) Address to which the material is dispatched.
(d) Description and dimensions of the material.
(e) Specifications or grades of both the aluminium alloy and the steel and any intermediate layer.
(f) Cast numbers of the steel and aluminium plates.
(g) Identification number of the composite plate.
(h) Mechanical test results (not required on shipping statement).

Contents

■ *Section 1* Castings for propellers

1.1 Scope

1.1.1 This Section gives the requirements for copper alloy castings for one-piece propellers and separately cast blades and bosses for fixed pitch and controllable pitch propellers (CPP). These include contra-rotating propellers and propulsors fitted to podded drives and azimuth units.

1.1.2 These castings are to be manufactured and tested in accordance with the appropriate requirements of Chapters *Ch 1 General Requirements* and *Ch 2 Testing Procedures for Metallic Materials* and the specific requirements of this Section.

1.1.3 As an alternative to *Ch 9, 1.1 Scope 1.1.2*, castings which comply with National or proprietary specifications may be accepted provided that these specifications give reasonable equivalence to the requirements of this Section or alternatively are approved for a specific application.

1.1.4 The appropriate requirements of this Section may also be applied to the repair and inspection of propellers which have been damaged during service.

1.1.5 Generally, survey and certification are to be carried out in accordance with the requirements of *Ch 1 General Requirements*.

1.2 Manufacture

1.2.1 All castings are to be manufactured at foundries approved by Lloyd's Register (hereinafter referred as 'LR').

1.2.2 The pouring is to be carried out into dried moulds using degassed liquid metal. The pouring is to avoid turbulent flow. Special devices and/or procedures are to be used to prevent slag flowing into the mould.

1.3 Quality of castings

1.3.1 All castings are to be free from surface or internal defects which would be prejudicial to their proper application in service.

1.3.2 The removal and repair of defects are dealt with in *Ch 9, 1.9 Rectification of defective castings* and *Ch 9, 1.10 Weld repair procedure*.

1.4 Chemical composition

1.4.1 The chemical compositions of samples from each melt are to comply with the manufacturing specification approved by LR and also with the overall limits given in *Table 9.1.1 Chemical composition of propeller and propeller blade castings*. In addition to carrying out chemical analysis for the elements given in the Table, it is expected that manufacturers will ensure that any harmful residual elements are within acceptable limits.

1.4.2 The use of alloys whose chemical compositions are different from those detailed in *Table 9.1.1 Chemical composition of propeller and propeller blade castings* will be given special consideration by LR.

1.4.3 The manufacturer is to maintain records of all chemical analyses, which are to be made available to the Surveyor so that he can satisfy himself that the chemical composition of each casting is within the specified limits.

1.4.4 When a melt is wholly prepared from ingots for which an analysis is already available, and provided that no significant alloy additions are made during melting, the ingot maker's certified analysis can be accepted subject to occasional checks as required by the Surveyor. If any foundry returns are added to the melts, the ingot manufacturer's chemical analyses are to be supplemented by frequent checks as required by the Surveyor.

Table 9.1.1 Chemical composition of propeller and propeller blade castings

Alloy designation	Chemical composition of ladle samples %							
	Cu	Sn	Zn	Pb	Ni	Fe	Al	Mn
Grade Cu 1 Manganese bronze (high tensile brass)	52–62	1,5 max.	35–40	0,5 max.	1,0 max.	0,5–2,5	0,5–3,0	0,5–4,0
Grade Cu 2 Ni-manganese bronze (high tensile brass)	50–57	0,1–1,5	33–38	0,5 max.	3,0–8,0	0,5–2,5	0,5–2,0	1,0–4,0
Grade Cu 3 Ni-aluminium bronze	77–82	0,1 max.	1,0 max.	0,03 max.	3,0–6,0 (*see* Note)	2,0–6,0 (*see* Note)	7,0–11,0	0,5–4,0
Grade Cu4 Mn–aluminium bronze	70–80	1,0 max.	6,0 max.	0,05 max.	1,5–3,0	2,0–5,0	6,5–9,0	8,0–20,0
Note For Naval ships, the nickel content is to be higher than the iron content.								

1.4.5 For alloys Grade Cu 1 and Cu 2, the zinc equivalent shall not exceed 45 per cent, and is to be calculated using the following formula:

$$zincequivalent\ \% = 100 - \frac{100 \times \%\,Cu}{100 + A}$$

where A is the algebraic sum of the following:

1 × % Sn

5 × % Al

–0,5 × % Mn

–0,1 × % Fe

–2,3 × % Ni

1.4.6 Samples for metallographic examination are to be prepared from the ends of test bars cast from every melt of Grade Cu 1 and Cu 2 alloys. The proportion of alpha-phase determined from the average of at least five counts is to be not less than 25 per cent.

1.5 Heat treatment

1.5.1 At the option of the manufacturer, castings may be supplied in the `as cast' or heat treated condition. However, if heat treatment is to be applied, full details are to be included in the manufacturing specification.

1.5.2 If any welds are made in the propeller casting, stress relief heat treatment is required in order to minimise the residual stresses. Requirements concerning such heat treatment are given in *Ch 9, 1.10 Weld repair procedure*.

1.6 Test material

1.6.1 Test samples are to be cast separately from each melt used for the manufacture of propeller or propeller blade castings.

1.6.2 The test samples are to be of the keel block type, generally in accordance with the dimensions given in *Figure 9.1.1 Keel block type test sample* and are to be cast in moulds made from the same type of material as used for the castings.

1.6.3 The method and procedures for the identification of the test specimens, and the castings they represent, are to be agreed with the Surveyor. The identification marks are to be transferred and maintained during the preparation of test specimens.

1.6.4 Where castings are supplied in the heat treated condition, the test samples are to be heat treated together with the castings which they represent.

1.7 Mechanical tests

1.7.1 At least one tensile test specimen representative of each cast is to be prepared. The dimensions of this test specimen are to be in accordance with *Figure 2.2.1 Test specimen dimensions for forgings and castings - I* in Chapter 2.

1.7.2 The results of all tensile tests are to comply with the requirements given in *Table 9.1.2 Mechanical properties for acceptance purposes: propeller and propeller blade castings*.

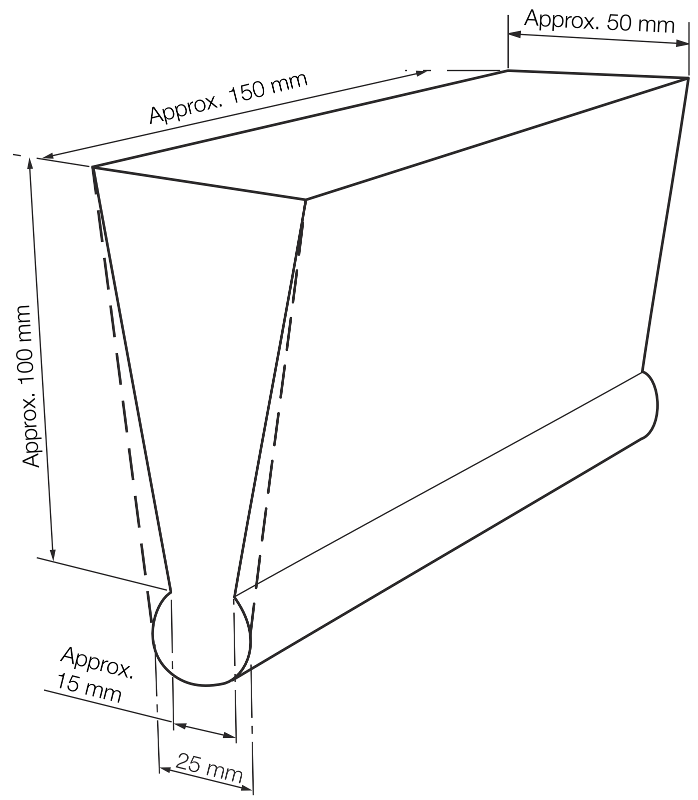


Figure 9.1.1 Keel block type test sample

Table 9.1.2 Mechanical properties for acceptance purposes: propeller and propeller blade castings

Alloy designation	0,2% proof stress N/mm^2 minimum	Tensile strength N/mm^2 minimum	Elongation on 5,65 $\sqrt{S_0}$ % minimum
Grade Cu 1 Manganese bronze (high tensile brass)	175	440	20
Grade Cu 2 Ni-manganese bronze (high tensile brass)	175	440	20
Grade Cu 3 Ni-aluminium bronze	245	590	16
Grade Cu 4 Mn-aluminium bronze	275	630	18

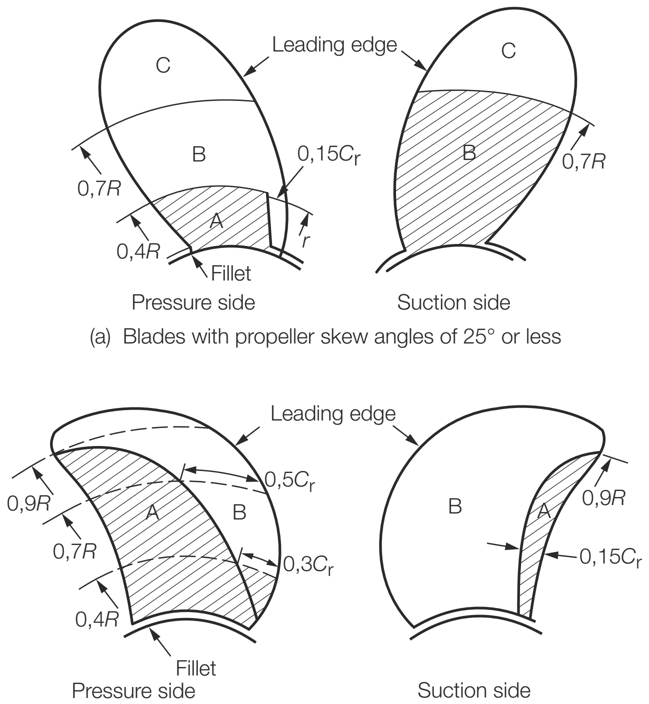
1.7.3 The mechanical properties of alloys whose chemical compositions do not accord with *Table 9.1.1 Chemical composition of propeller and propeller blade castings* are to comply with a manufacturing specification approved by LR.

1.8 Inspection and non-destructive examination

1.8.1 Propeller castings should be visually inspected at all stages of manufacture. The manufacturer is to draw any significant imperfections to the attention of the Surveyor. Such imperfections are to be verified in accordance with *Ch 9, 1.9 Rectification of defective castings*.

1.8.2 All finished castings are to be subjected to a comprehensive visual examination by the Surveyor, including internal surfaces such as the bore and bolt holes. Where unauthorised weld repairs are suspected by the Surveyor, the area is to be etched (e.g. by iron chloride) for the purpose of confirmation.

1.8.3 For the purpose of these requirements, the blades of propellers, including CPP blades, are divided into three severity Zones A, B and C as shown in *Figure 9.1.2 Severity zones in all propeller blades* and detailed in *Ch 9, 1.8 Inspection and non-destructive examination 1.8.4* for blades having skew angles of 25° or less and *Ch 9, 1.8 Inspection and non-destructive examination 1.8.5* for blades having skew angles of greater than 25°.



(b) Blades with propeller skew angles of greater than 25°

R = propeller radius
C_r = chord length at radius r

NOTE
For a definition of skew angle, *see* the relevant Rules

Figure 9.1.2 Severity zones in all propeller blades

1.8.4 **Skew angles of 25° or less:**

- Zone A is the area on the pressure side of the blade from and including the root fillet to 0,4R and bounded by the trailing edge and by a line at a distance 0,15 times the chord length from the leading edge.
- Zone B includes the areas inside 0,7R on both sides of the blade, excluding Zone A.
- Zone C includes the areas outside 0,7R on both sides of the blade.

1.8.5 **Skew angles of greater than 25°:**

- Zone A is the area on the pressure side of the blade bounded by, and including, the root fillet and a line running from the junction of the leading edge with the root fillet to the trailing edge at 0,9R and passing through the mid-point of the chord at 0,7R and a point situated at 0,3 of the chord length from the leading edge at 0,4R.
- Zone A also includes the area along the trailing edge on the suction side of the blade from the root to 0,9R and with its inner boundary at 0,15 of the chord length tapering to meet the trailing edge at 0,9R.
- Zone B constitutes the whole of the remainder of the blade surfaces.

1.8.6 In propeller blades with continuously loaded tips (CLT), the whole of the tip plate and the adjoining blade to a distance of 100 mm is to be regarded as severity Zone B, *see Figure 9.1.3 Severity Zone B at continuously loaded blade tip*. For propellers with diameters less than 2 m, the width of this zone may be reduced to one tenth of the propeller radius.

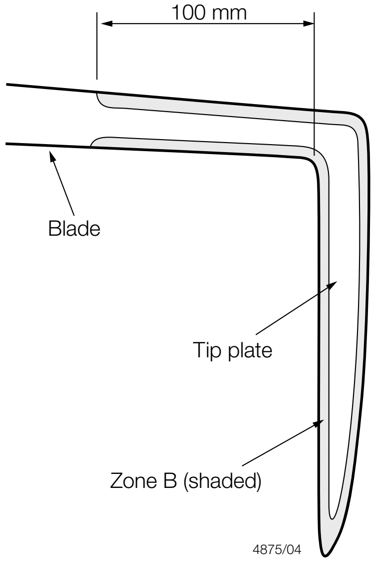


Figure 9.1.3 Severity Zone B at continuously loaded blade tip

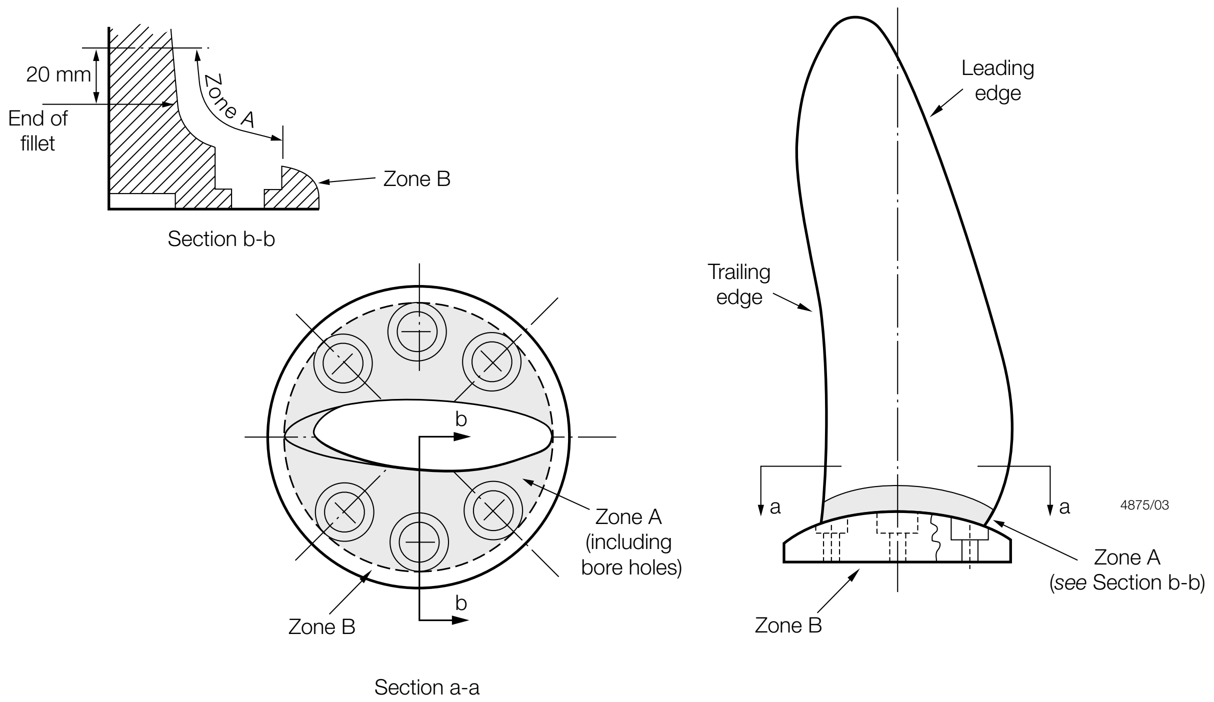
1.8.7 In addition, the palm of a CPP blade is divided into severity Zones A and B as shown in *Figure 9.1.4 Severity zones for controllable pitch propeller blades*.

1.8.8 If a CPP blade has an integrally cast journal, the fillets of the journal and the adjoining material up to a distance of 20 mm from the fillet run-outs are to be regarded as Zone B, as indicated in *Figure 9.1.5 Severity zones in integrally cast CPP blade journals*. The remainder of the surface of the journal may be regarded as Zone C.

1.8.9 Hubs of controllable pitch propellers are to contain a Zone A region at each blade port as shown in *Figure 9.1.6 Severity zones for controllable pitch propeller hub*. The remainder may be regarded as Zone C.

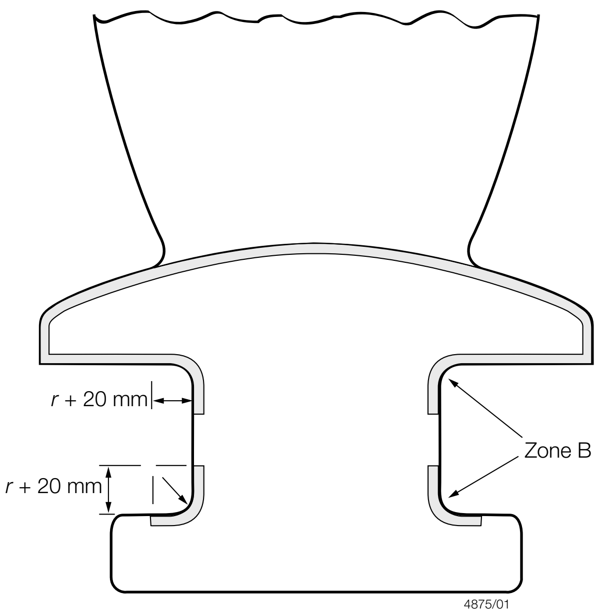
1.8.10 On completion of machining and grinding, the whole surface of each casting is to be subjected to a dye penetrant inspection in accordance with a procedure acceptable to LR.

1.8.11 All dye penetrant inspections on Zone A areas in the finished condition are to be made in the presence of the Surveyor.



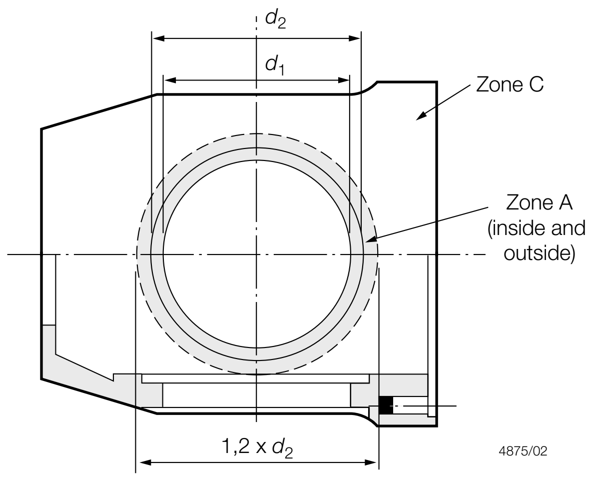
The surfaces of blades are to be divided into severity zones in accordance with Fig. 9.1.2

Figure 9.1.4 Severity zones for controllable pitch propeller blades



The surfaces of the journal which are not shaded
are to be regarded as severity Zone C

Figure 9.1.5 Severity zones in integrally cast CPP blade journals



(d_1 and d_2 = diameters)

Figure 9.1.6 Severity zones for controllable pitch propeller hub

1.8.12 Dye penetrant inspections on Zones B and C are to be performed by the manufacturer and may be witnessed at the Surveyor's request.

1.8.13 The surface to be inspected shall be divided into reference areas of 100 cm^2. The indications detected shall, with respect to their size and number, not exceed the values given in *Table 9.1.3 Allowable number and size of dye penetrant indications in a reference area of 100 cm2 (see Note 1)* . The area shall be taken in the most unfavourable location relative to the indication being evaluated.

1.8.14 Indications exceeding the acceptance standard in *Table 9.1.3 Allowable number and size of dye penetrant indications in a reference area of 100 cm2 (see Note 1)* shall be repaired in accordance with *Ch 9, 1.9 Rectification of defective castings*.

1.8.15 All defects requiring repair by welding in new propeller castings are to be recorded on sketches showing their locations and dimensions. Copies of these sketches are to be presented to the Surveyor prior to repair.

1.8.16 Where repairs have been made either by grinding or welding, the repaired areas are to be subjected to dye penetrant inspection in the presence of the Surveyor, regardless of their location.

1.8.17 Where no welds have to be made on a casting, the manufacturer is to provide the Surveyor with a statement that this is the case.

1.8.18 Where it is suspected that a casting contains internal defects, radiographic and/or ultrasonic examination may be required by the Surveyor. The acceptance criteria are to be agreed between the manufacturer and LR in accordance with a recognised standard. The standard ASTM E272-99 (Severity Level 2) or equivalent is to be the radiographic acceptance standard for copper alloy castings. Ultrasonic testing of Cu 1 and Cu 2 is not considered in these Rules. For Cu 3 and Cu 4, ultrasonic inspection of defects may be possible and is to comply with the requirements for steel castings.

1.8.19 The measurement of dimensional accuracy is the responsibility of the manufacturer but the report on dimensional inspection is to be presented to the Surveyor who may require checks to be made and to witness such checks.

1.8.20 Static balancing is to be carried out on all propellers in accordance with the approved plan. Dynamic balancing is necessary for propellers running above 500 rpm.

1.9 Rectification of defective castings

1.9.1 The rectification of defective propeller and propeller blade castings is to be carried out in accordance with the requirements given in *Ch 9, 1.9 Rectification of defective castings 1.9.2*.

1.9.2 The rectification of small indications within the acceptance standard of *Table 9.1.3 Allowable number and size of dye penetrant indications in a reference area of 100 cm2 (see Note 1)* is not generally required except where they occur in closely spaced groups.

1.9.3 Where, in the surface of the end face or bore of a propeller boss, local pores are present which do not themselves adversely affect the strength of the casting, they may be filled with a suitable plastic filler after the appropriate preparation of the defective area. The foundry is to maintain records and details of all castings which have been so rectified.

1.9.4 Where unacceptable defects are found in a casting, they are to be removed by mechanical means, and the surfaces of the resulting depressions are subsequently to be ground smooth. Complete elimination of the defects is to be proved by adequate dye penetrant inspection.

1.9.5 Shallow grooves or depressions resulting from the removal of defects may, at the discretion of the Surveyor, be accepted provided that they will cause no appreciable reduction in the strength of the castings and that they are suitably blended by grinding.

1.9.6 Welded repairs are to be undertaken only when they are considered to be necessary and approved by the Surveyor. In general, welds having an area less than 5 cm^2 are to be avoided.

1.9.7 All weld repairs are to be carried out in accordance with qualified procedures by suitably qualified welders, and are to be completed to the satisfaction of the Surveyor. Records are to be made available to the Surveyor.

1.9.8 Welding is generally not permitted in Zone A and will only be allowed after special consideration.

1.9.9 Prior approval by the Surveyor is required for any welds in Zone B. Complete details of the repair procedure are to be submitted for each case.

1.9.10 Repair by welding is allowed in Zone C provided that there is compliance with *Ch 9, 1.9 Rectification of defective castings 1.9.6* and *Ch 9, 1.9 Rectification of defective castings 1.9.7*.

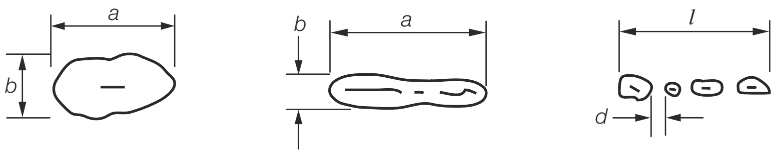
1.9.11 The maximum area of any single repair and the maximum total area of repair in any one zone or region are given in *Table 9.1.4 Permissible rectification of new propellers by welding*.

Table 9.1.3 Allowable number and size of dye penetrant indications in a reference area of 100 cm^2 (*see* Note 1)

Severity Zones	Max. total number of indications	Type of indications (*see* Note 2)	Max. number of each type (*see* Notes 3 and 4)	Max. acceptable value for 'a' or 'l' of indications (mm) (*see* Note 2)
A	7	Non-linear	5	4
		Linear	2	3
		Aligned	2	3
B	14	Non-linear	10	6
		Linear	4	6
		Aligned	4	6
C	20	Non linear	14	8
		Linear	6	6
		Aligned	6	6

Note 1. The reference area is defined as an area of 0,1 m^2, which may be square or rectangular, with the major dimension not exceeding 250 mm. The area shall be taken in the most unfavourable location relative to the indication being evaluated.

Note 2. Non-linear, linear and aligned indications are defined as follows:



$\frac{a}{b} < 3$ non-linear

$\frac{a}{b} \geq 3$ linear

$d \leq 2$ mm aligned

Note 3. Only indications that have any dimension greater than 1,5 mm shall be considered relevant.

Note 4. Single non-linear indications less than 2 mm in Zone A and less than 3 mm in other zones may be disregarded.

Note 5. The total number of non-linear indications may be increased to the maximum total number, or part thereof, represented by the absence of linear or aligned indications.

1.9.12 Where it is proposed to exceed the areas given in *Table 9.1.4 Permissible rectification of new propellers by welding*, the nature and extent of the repair work are to be approved by the Surveyor before commencement of the repair.

Table 9.1.4 Permissible rectification of new propellers by welding

Severity zone or region	Maximum individual area of repair	Maximum total area of repairs
Zone A	Weld repairs not generally permitted	
Zone B	Defects that are not deeper than (t/40) mm or 2 mm, whichever is greater, below the minimum local thickness are to be removed by grinding. Defects which are deeper than allowable for removal by grinding may be repaired by welding.	
Zone C	60 cm^2 or 0,6% x *S* whichever is the greater	200 cm^2 or 2% x *S*, whichever is the greater in combined Zones B and C but not more than 100 cm^2 or 0,8% x *S*, whichever is the greater, in Zone B on the pressure side
Other regions (*see* Note)	17 cm^2 or 1,5% area of the region whichever is the greater	50 cm^2 or 5% × area of the region whichever is the greater

where *t* = minimum local thickness in mm

S = area of one side of a blade = 0,79 $\frac{D^2 B}{N}$

D = finished diameter of propeller

B = developed area ratio

N = number of blades

Note Other regions include: (a) the bore; (b) the forward and aft faces of the boss; (c) the outer surface of the boss to the start of the blade root fillets; (d) the inner face of a CPP blade palm; (e) all surfaces of CPP nose cones; (f) the surfaces of integral journals to CPP blades other than the fillets.

1.10 Weld repair procedure

1.10.1 Welding is to be carried out under cover in positions free from draughts and adverse weather conditions.

1.10.2 The manufacturer is to submit a detailed welding procedure specification covering the weld preparation, welding parameters, filler metal, preheating, post-weld heat treatment and inspection procedures.

1.10.3 Before welding is started, Welding Procedure Qualification tests are to be carried out and witnessed by the Surveyor. Each welder is to be qualified to carry out the proposed welding using the same process, consumable and position which are to be used for the repair.

1.10.4 Defects to be repaired by welding are to be removed completely by mechanical means (e.g. grinding, chipping or milling). Removal of defects in accordance with the requirements for Zone A is to be demonstrated by dye penetrant inspection in

the presence of the Surveyor. The excavation is to be prepared in a manner which will allow good fusion and is to be clean and dry.

1.10.5 Metal arc welding with the electrodes or filler wire used in the procedure tests is to be used for all types of repairs. Welds should preferably be made in the downhand (flat) position. Where necessary, suitable preheat is to be applied before welding, and the preheat temperature is to be maintained until welding is completed.

1.10.6 When flux coated electrodes are used they are to be dried immediately before use, in accordance with the manufacturer's instructions.

1.10.7 All slag, undercuts and other defects are to be removed before the subsequent run is deposited.

1.10.8 With the exception given in *Ch 9, 1.10 Weld repair procedure 1.10.9*, all weld repairs in areas of solid propellers exposed to sea-water, and all repairs to separately cast blades, are to be stress relief heat treated.

1.10.9 Stress relief heat treatment is not mandatory after welding Grade Cu 3 castings in Zone C unless a welding consumable susceptible to stress corrosion (e.g. complying with the composition range of Grade Cu 4) is used. All welds in Zones A and B however, must be stress relieved by heat treatment, regardless of alloy.

1.10.10 Propeller and propeller blades are to be stress relieved within the following temperature ranges:

alloy Grades Cu 1 and Cu 2	350°C to 550°C
alloy Grade Cu 3	450°C to 500°C
alloy Grade Cu 4	450°C to 600°C

Soaking times are to be in accordance with *Table 9.1.5 Soaking times for stress relief heat treatment of copper alloy propellers*, and subsequent cooling from the soaking temperature is to be suitably controlled to minimise residual stresses and is not to exceed 50°C per hour until the temperature is below 200°C. Care should be taken to avoid heating castings in the Grade Cu 3 alloy at temperatures between 300 and 400°C for prolonged periods.

Table 9.1.5 Soaking times for stress relief heat treatment of copper alloy propellers

Stress relief temperature °C (*see* Notes)	Alloy Grade Cu1 and Cu2		Alloy Grade Cu3 and Cu4	
	Hours per 25 mm of thickness	Maximum recommended total time hours	Hours per 25 mm of thickness	Maximum recommended total time hours
350	5	15	—	—
400	1	5	—	—
450	½	2	5	15
500	¼	1	1	5
550	¼	½	½	2
600	–	–	¼	1

Note 1. Treatment at 550°C is not applicable to alloy Grade Cu3.

Note 2. Treatment at 600°C is only applicable to alloy Grade Cu4.

1.10.11 Stress relief heat treatment is to be carried out, where possible, in furnaces having suitable atmosphere and temperature control. Sufficient thermocouples are to be attached to the casting to measure the temperature at positions of extremes of thickness.

1.10.12 As an alternative to *Ch 9, 1.10 Weld repair procedure 1.10.11*, local stress relief heat treatment may be accepted, provided that the Surveyor is satisfied that the technique will be effective and that adequate precautions are taken to prevent the introduction of detrimental temperature gradients. Where local stress relief heat treatment is approved, adequate temperature control is to be provided. The area of the propeller or blade adjacent to the repair is to be suitably monitored and insulated to ensure that the required temperature is maintained and that temperature gradients are moderate. Care should be taken to select the shape of an area to be heat treated which will minimise residual stresses.

1.10.13 On completion, welds are to be ground smooth for visual examination and dye penetrant inspection. Where a propeller or propeller blade is to be stress relief heat treated, a visual examination is to be made before heat treatment, and both visual and dye penetrant examinations are to be made after the stress relief heat treatment. Irrespective of location, all weld repairs are to be assessed according to Zone A in *Table 9.1.3 Allowable number and size of dye penetrant indications in a reference area of 100 cm2 (see Note 1)*

1.10.14 The foundry is to maintain full records detailing the weld procedure, heat treatment and extent and location on drawings of repairs made to each casting. These records are to be available for review by the Surveyor, and copies of individual records are to be supplied to the Surveyor on request.

1.10.15 LR reserves the right to restrict the amount of repair work accepted from a manufacturer when it appears that repetitive defects are the result of improper foundry techniques or practices.

1.11 Identification

1.11.1 Castings are to be clearly marked by the manufacturer in accordance with the requirements of *Ch 1 General Requirements*. The following details are to be shown on all castings which have been accepted:

(a) Identification mark which will enable the full history of the item to be traced.
(b) Alloy grade.
(c) LR or Lloyd's Register and the abbreviated name of LR local office.
(d) Personal stamp of Surveyor responsible for the final inspection.
(e) Date of final inspection.
(f) Skew angle if in excess of 25°. *See Pt 5, Ch 7, 1 Plans and particulars* of the Rules for Ships for the definition of skew angle.

1.12 Certification of materials

1.12.1 A LR certificate is to be issued for each propeller, *see Ch 1, 3.1 General*.

1.12.2 The manufacturer is to provide the Surveyor with the following particulars for each casting:

(a) Purchaser's name and order number.
(b) Description of casting.
(c) Alloy designation and/or trade name.
(d) Identification number of casting.
(e) Cast identification number if different from (d).
(f) Details of heat treatment, where applicable.
(g) Skew angle if in excess of 25°. *See* the relevant Rules for the definition of skew angle.
(h) Final weight of casting.
(i) Results of non-destructive tests and details of test procedures.
(j) Proportion of alpha-structure for Cu1 and Cu2 alloys.
(k) Results of mechanical tests.
(l) A sketch showing the location and extent of welding repairs (if any).

■ *Section 2*
Castings for valves, liners and bushes

2.1 Scope

2.1.1 This Section makes provision for copper alloy castings for valves, liners, bushes and other fittings intended for use in the construction of ships, other marine structures, machinery and pressure piping systems.

2.1.2 Castings are to be manufactured and tested in accordance with Chapters *Ch 1 General Requirements* and *Ch 2 Testing Procedures for Metallic Materials*, and also with the requirements given in this Section.

2.1.3 As an alternative to *Ch 9, 2.1 Scope 2.1.2*, castings which comply with National or proprietary specifications may be accepted provided that these specifications give reasonable equivalence to the requirements of this Section or alternatively are approved for a specific application. Generally, survey and certification are to be carried out in accordance with the requirements of *Ch 1 General Requirements*.

2.2 Manufacture

2.2.1 Castings are to be manufactured at foundries approved by LR.

2.3 Quality of castings

2.3.1 All castings are to be free from surface or internal defects which would be prejudicial to their proper application in service.

2.4 Chemical composition

2.4.1 The chemical composition is to comply with the requirements of a National or International Standard and, where appropriate, with the limits for the principal elements of the preferred alloys listed in *Table 9.2.1 Chemical compositions of long freezing range alloys: principal elements only* and *Table 9.2.2 Chemical compositions of short freezing range alloys: principal elements only*.

Table 9.2.1 Chemical compositions of long freezing range alloys: principal elements only

Alloy type	Designation	Chemical composition						Typical applications
		Cu	Sn	Zn	Pb	Ni	P	
Phosphor bronze	Cu Sn11 P	87,0 – 89,5	10,0 – 11,5	0,05 max.	0,25 max.	0,10 max	0,5 – 1,0	Liners, bushes, valves and fittings
	Cu Sn12	85,0 – 88,5	11,0 – 13,0	0,50 max.	0,7 max.	2,0 max	0,60 max	
Gunmetal	Cu Sn10 Zn2	Remainder	9,5 – 10,5	1,75 – 2,75	1,5 max.	1,0 max	–	Liners, valves and fittings
Leaded gunmetal	Cu Sn5 Zn5 Pb5	83,0 – 87,0	4,0 – 6,0	4,0 – 6,0	4,0 – 6,0	2,0 max	0,10 max	Bushes, valves and fittings
	Cu Sn7 Zn2 Pb3	85,0 – 89,0	6,0 – 8,0	1,5 – 3,0	2,5 – 3,5	2,0 max	0,10 max	
	Cu Sn7 Zn4 Pb7	81,0 – 85,0	6,0 – 8,0	2,0 – 5,0	5,0 – 8,0	2,0 max	0,10 max	
	Cu Sn6 Zn4 Pb2	86,0 – 90,0	5,5 – 6,5	3,0 – 5,0	1,0 – 2,0	1,0 max	0,05 max	
Leaded bronze	Cu Sn10 Pb10	78,0 – 82,0	9,0 – 11,0	2,0 max.	8,0 – 11,0	2,0 max	0,10 max	Bushes
	Cu Sn5 Pb9	80,0 – 87,0	4,0 – 6,0	2,0 max.	8,0 – 10,0	2,0 max	0,10 max	
	Cu Sn7 Pb15	74,0 – 80,0	6,0 – 8,0	2,0 max.	13,0 – 17,0	0,5 – 2,0	0,10 max	
	Cu Sn5 Pb20	70,0 – 78,0	4,0– 6,0	2,0 max.	18,0 – 23,0	0,5 – 2,5	0,10 max	

Table 9.2.2 Chemical compositions of short freezing range alloys: principal elements only

Alloy type	Designation	Chemical composition								Typical applications
		Cu	Ni	Fe	Mn	Cr	Nb	Si	Al	

Copper 30% nickel	Cu Ni30 Fe1 Mn1	64,5 min.	29,0–31,0	0,5–1,5	0,6–1,2	–	–	0,1 max.	–	Flanges, valves and fittings
	Cu Ni30 Fe1 Mn1 Nb Si	Remainder	29,0–31,0	0,5–1,5	0,6–1,2	–	0,5–1,0	0,3–0,7	–	
	Cu Ni30 Cr2 Fe Mn Si (*see* Note)	Remainder	29,0–32,0	0,5–1,0	0,5–1,0	1,5–2,0	–	0,15–0,50	–	
Copper 10% nickel	Cu Ni10 Fe1 Mn1	84,5 min.	9,0–11,0	1,0–1,8	1,0–1,5	–	1,0 max.	0, 10 max.	–	Flanges, valves and fittings
Aluminium	Cu Al10 Fe5 Ni5	76,0–83,0	4,0–6,0 (*See* Note 2)	4,0–5,5 (*See* Note 2)	3,0 max.	–	–	0,1 max.	8,5–10,5	Bushes, valves and fittings
bronze	Cu Al11 Fe6 Ni6	72,0–78,0	4,0–7,5 (*See* Note 2)	4,0–7,0 (*See* Note 2)	2,5 max.	–	–	0,1 max.	10,0–12,0	

Note 1. Normally alloy Cu Ni30 Cr2 Fe Mn Si contains 0,1 to 0,25% titanium and 0,05 to 0,15% zirconium.

Note 2. For Naval ships, the nickel content is to be higher than the iron content.

2.4.2 With the exception given in *Ch 9, 2.4 Chemical composition 2.4.3*, chemical analysis is required on each cast.

2.4.3 Where a cast is wholly prepared from ingots for which an analysis is already available, and provided that no significant alloy additions are made during melting, the ingot maker's certified analysis can be accepted subject to occasional check tests as requested by the Surveyor. The frequency of these check tests should, as a minimum, be one in every ten casts. If one of these check analyses fails to comply with the specification, checks are to be made on the previous and subsequent melts. If one or both of these further analyses is unsatisfactory, chemical analysis is to be carried out on all further melts until the Surveyor is satisfied that a return can be made to the use of occasional check tests.

2.5 Heat treatment

2.5.1 Where required by the specification, castings may be supplied in either the `as-cast' or heat treated condition.

2.5.2 Where castings are supplied in a heat treated condition, the test samples are to be heat treated with the castings they represent prior to the preparation of the tensile test specimens.

2.6 Test material

2.6.1 Test material sufficient for the tests specified in *Ch 9, 2.6 Test material 2.6.4* and for possible re-test purposes is to be provided for each cast of material.

2.6.2 The test material is to be separately cast into moulds made of the same material as that used for the castings they represent.

2.6.3 For the alloys listed in *Table 9.2.1 Chemical compositions of long freezing range alloys: principal elements only*, sand cast test bars are generally to be in accordance with *Figure 9.2.1 Sand cast test bars for long freezing range alloys*.

2.6.4 For the alloys listed in *Table 9.2.2 Chemical compositions of short freezing range alloys: principal elements only*, keel block type test samples are to be in accordance with *Figure 9.1.1 Keel block type test sample*.

2.6.5 If it is proposed to use any other form of test bar, this is to be agreed in advance with the Surveyor.

2.6.6 As an alternative, for liners and bushes, the test material may be taken from the ends of the castings.

2.7 Mechanical tests

2.7.1 A tensile test specimen is to be prepared from each test sample. The dimensions of the specimens are to comply with *Figure 2.2.1 Test specimen dimensions for forgings and castings - I* or *Figure 2.2.2 Test specimen dimensions for forgings and castings - II and aluminum alloys* in Chapter 2.

2.7.2 The results of all tests are to comply with the appropriate requirements given in *Table 9.2.3 Mechanical properties of long freezing range alloys for acceptance purposes* and *Table 9.2.4 Mechanical properties of short freezing range alloys for acceptance purposes*.

Table 9.2.3 Mechanical properties of long freezing range alloys for acceptance purposes

Alloy type	Designation	0,2% proof stress N/mm^2 minimum (*See* Note 1)		Tensile strength N/mm^2 minimum		Elongation on 5,65 $\sqrt{S_o}$ % minimum	
		Sand	Centrifugal	Sand	Centrifugal	Sand	Centrifugal
Phosphor bronze	Cu Sn11 P	130	170	250	330	5	4
	Cu Sn12	140	150	260	280	7	5
Gunmetal	Cu Sn10 Zn2	130	130	270	250	13	5
Leaded gunmetal	Cu Sn5 Zn5 Pb5	90	110	200	250	13	13
	Cu Sn7 Zn2 Pb3	130	130	230	260	14	12
	Cu Sn7 Zn4 Pb7	120	120	230	260	15	12
	Cu Sn6 Zn4 Pb2	110	110	220	240	15	12
Leaded bronze	Cu Sn10 Pb10	80	110	180	220	8	6
	Cu Sn5 Pb9	60	90	160	200	7	6
	Cu Sn7 Pb15	80	90	170	200	8	7
	Cu Sn5 Pb20	70	80	150	170	5	6

Note 1. The 0,2% proof stress values are given for information purposes only and, unless otherwise agreed, are not required to be verified by test.

Note 2. Castings may be supplied in the chill cast condition in which case the mechanical properties requirements are to be in accordance with a specification agreed by LR.

Table 9.2.4 Mechanical properties of short freezing range alloys for acceptance purposes

Alloy type	Designation	0,2% proof stress N/mm^2 minimum		Tensile strength N/mm^2 minimum		Elongation on 5,65 $\sqrt{S_o}$ % minimum	
		Sand	Centrifugal	Sand	Centrifugal	Sand	Centrifugal
Copper 30% Nickel	Cu Ni30 Fe1 Mn1	120	120	340	340	18	18
	Cu Ni30 Fe1 Mn1 Nb Si	230	–	440	–	18	–
	Cu Ni30 Cr2 Fe Mn Si	250	–	440	–	18	–
Copper 10% Nickel	Cu Ni10 Fe1 Mn1	120	100	280	280	20	25
Aluminium Bronze	Cu Al10 Fe5 Ni5	250	280	600	650	13	13
	Cu Al11 Fe6 Ni6	320	380	680	750	5	5

2.8 Inspection

2.8.1 All castings are to be cleaned and adequately prepared for inspection. Before acceptance, all castings are to be presented to the Surveyor for visual examination. This is to include the examination of internal surfaces, where applicable.

2.8.2 For valves and other pressure components, dye penetrant inspection is required and the Surveyor is to witness the tests. Unless otherwise agreed, the acceptance criteria to be applied are to meet the requirements of *Table 9.2.5 Visual and surface NDE acceptance criteria for valves and pressure components*, or equivalent.

Table 9.2.5 Visual and surface NDE acceptance criteria for valves and pressure components

Defect type	Acceptance criteria for visual and surface NDE, *see* Note
Linear indications	Not permitted
Porosity	Individual pores are not to exceed 3 mm diameter bleed out, and the sum of the diameters of all indications in an area of 70 x 70 mm is not to exceed 24 mm^2
Note Inspection is to be in accordance with a procedure acceptable to LR.	

2.8.3 The accuracy and verification of dimensions are the responsibility of the manufacturer. However, the report on dimensional inspection is to be presented to the Surveyor who may request to witness confirmatory measurements.

2.9 Rectification of defective castings

2.9.1 Subject to the prior approval of the Surveyor, castings containing local porosity may be rectified by impregnation with a suitable plastic filler provided that the extent of the porosity is such that it does not adversely affect the strength of the casting.

2.9.2 Proposals to repair a defective casting by welding are to be submitted to the Surveyor before this work is commenced. The Surveyor is to be satisfied that the number, position and size of the defects are such that the castings can be efficiently repaired.

2.9.3 Where approval is given for the repair by welding, complete elimination of the defects is to be proven by adequate non-destructive testing.

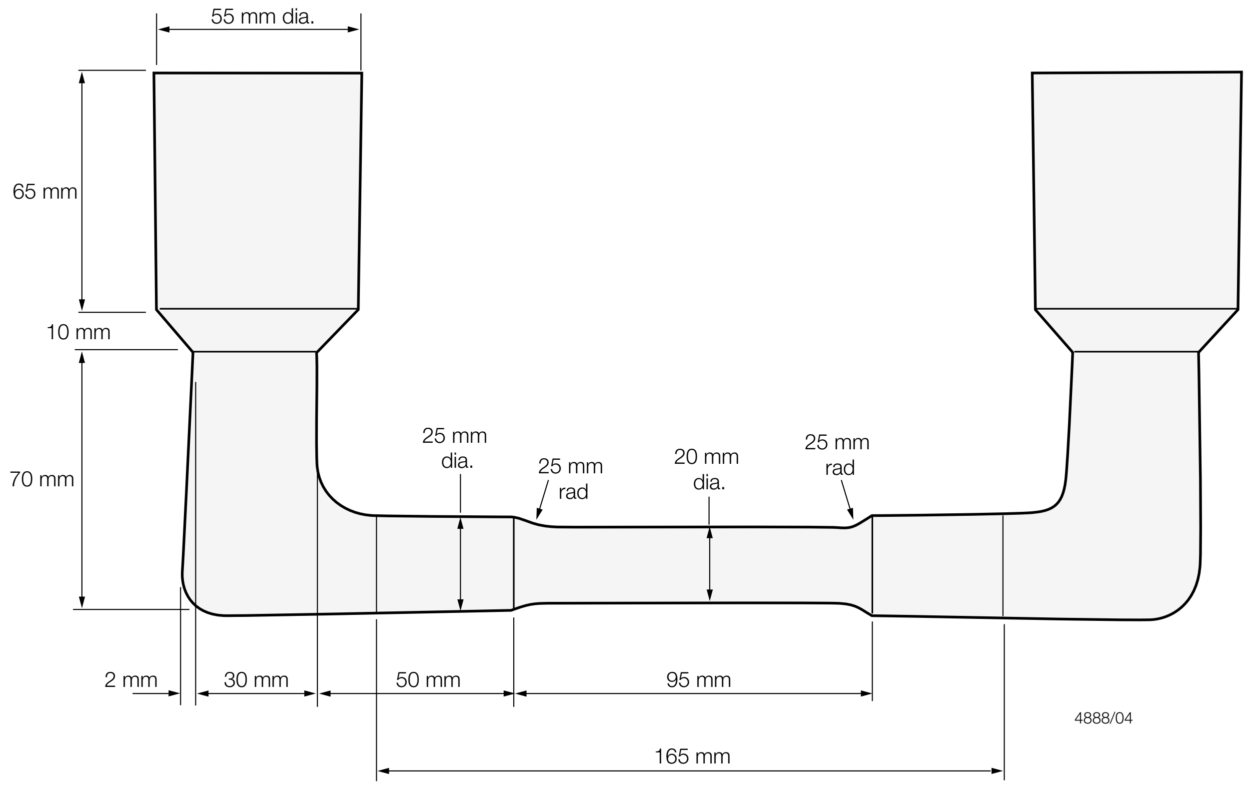


Figure 9.2.1 Sand cast test bars for long freezing range alloys

2.9.4 All welding is to be in accordance with an approved and qualified weld procedure and carried out by a qualified welder.

2.9.5 A statement and/or sketch detailing the extent and position of all weld repairs is to be prepared by the manufacturer as a permanent record. These records are to be available for review by the Surveyor, and copies of individual records are to be supplied to the Surveyor on request.

2.9.6 The alloys listed in *Table 9.2.1 Chemical compositions of long freezing range alloys: principal elements only* are not satisfactory for repair by welding which is generally not permitted. Weld repairs may, however, be considered in special circumstances provided that a suitable procedure, with proof of previous satisfactory repairs is submitted to the Surveyor.

2.9.7 The welding during manufacture of liners is not permitted in any alloy containing more than 0,5 per cent lead.

2.10 Pressure testing

2.10.1 Where required by the relevant Rules, castings are to be pressure tested before final acceptance. Unless otherwise agreed, these tests are to be carried out in the presence of the Surveyors and are to be to their satisfaction.

2.11 Identification

2.11.1 The manufacturer is to adopt a system of identification which will enable all finished castings to be traced to the original cast, and the Surveyor is to be given full facilities for so tracing the casting when required.

2.11.2 Before acceptance, all castings which have been tested and inspected with satisfactory results are to be clearly marked by the manufacturer with the following details:

(a) Identification number, cast number or other markings which will enable the full history of the casting to be traced.
(b) LR or Lloyd's Register and the abbreviated name of LR's local office.
(c) Personal stamp of the Surveyor responsible for inspection.
(d) Test pressure, where applicable.
(e) Date of final inspection.

2.11.3 Where small castings are manufactured in large numbers, modified arrangements for identification may be specially agreed with the Surveyor.

2.12 Certification of materials

2.12.1 A LR certificate is to be issued, *see Ch 1, 3.1 General*.

2.12.2 The manufacturer is to provide the Surveyor with the following particulars for each casting or batch of castings which has been accepted:

(a) Purchaser's name and order number.
(b) Description of castings and alloy grade.
(c) Identification number.
(d) Ingot or cast analysis.
(e) Full details of heat treatment, where applicable.
(f) Mechanical test results.
(g) Test pressure, where applicable.

2.12.3 In addition to *Ch 9, 2.12 Certification of materials 2.12.2*, the manufacturer is to provide, where applicable, a statement and/or sketch detailing the extent and position of all weld repairs made to each casting.

■ *Section 3* **Tubes**

3.1 Scope

3.1.1 Provision is made in this Section for seamless copper and copper alloy tubes intended for use in condensers, heat exchangers and pressure piping systems.

3.1.2 Tubes for Class I and II pressure systems (as defined in the relevant Rules), are to be manufactured and tested in accordance with the requirements of Chapters *Ch 1 General Requirements* and *Ch 2 Testing Procedures for Metallic Materials* and the requirements of this Section.

3.1.3 As an alternative to *Ch 9, 3.1 Scope 3.1.2*, tubes which comply with National or proprietary specifications may be accepted provided that these specifications give reasonable equivalence to the requirements of this Section or alternatively are approved for a specific application. Generally, survey and certification are to be carried out in accordance with the requirements of *Ch 1 General Requirements*.

3.1.4 Tubes for Class III pressure systems are to be manufactured and tested in accordance with the requirements of a National or International Standard recognised by LR. The manufacturer's test certificate will be acceptable and is to be provided for each batch of material.

3.2 Manufacture

3.2.1 Tubes for Class I and II pressure systems are to be manufactured at a works approved by LR for the grade of material being supplied.

3.2.2 Tubes for Class III pressure systems are not required to be manufactured at a works approved by LR.

3.3 Quality

3.3.1 Tubes are to be clean and free from surface and internal defects and residues from manufacturing operations.

3.3.2 The tubes are to be supplied in smooth, round, straight lengths and the manufacturer is to guarantee freedom from deleterious films in the bore. The ends are to be cut clean and square with the axis of the tube and are to be de-burred.

3.4 Dimensional tolerances

3.4.1 The tolerances on the wall thickness and diameter of the tubes are to be in accordance with a National or International Standard recognised by LR.

3.4.2 The measurement of dimensional accuracy and compliance with the specification are the responsibility of the manufacturer, but the reports are to be made available to the LR Surveyors, who may require checks to be made in their presence.

3.5 Chemical composition

3.5.1 The chemical composition is to comply with the requirements of a National or International Standard recognised by LR and comply with the base limits for the principal elements given in *Table 9.3.1 Chemical composition of principal elements only*.

Table 9.3.1 Chemical composition of principal elements only

Designation	Chemical composition %								
	Cu	As	P	Fe	Pb	Ni	Al	Mn	Zn
Copper-phosphorus deoxidised–non-arsenical	99,85 min.	—	0,013–0,050	—	—	—	—	—	—
Copper-phosphorus deoxidised–arsenical	99,2 min.	0,30–0,50	0,013–0,050	—	—	—	—	—	—
Aluminium brass	76,0–79,0	0,02–0,06	—	0,06 max.	0,07 max.	—	1,8–2,5	—	Remainder
90/10 Copper-nickel-iron (*see* Note)	Remainder	—	—	1,0-2,0	—	9,0–11,0	—	0,5–1,0	—
70/30 Copper-nickel-iron (*see* Note)	Remainder	—	—	0,40–1,00	—	29,0–33,0	—	0,5–1,5	—

NOTE

Where the purchaser specifies that the product is intended for subsequent welding applications, the following limits will apply:

Zn	0,50% max.	S	0,02% max.
Pb	0,02% max.	C	0,05% max.
P	0,02% max.		

3.6 Heat treatment

3.6.1 Copper-phosphorus and aluminium brass tubes are to be supplied in the annealed condition. Aluminium brass tubes may additionally be required to be given a suitable stress relieving heat treatment when subjected to a cold straightening operation after annealing.

3.6.2 Tubes in the copper-nickel iron alloys are to be supplied in a solution heat treated condition to ensure that no iron rich phases are present.

3.7 Mechanical tests

3.7.1 Tubes are to be presented for test in batches of 300 lengths. A batch is to consist of tubes of the same size, manufactured from the same material grade.

3.7.2 At least one length is to be selected at random from each batch and subjected to the following tests:

(a) Tensile test.
(b) Flattening test.
(c) Drift expanding test.

3.7.3 The procedures for mechanical tests and the dimensions of the test specimens are to be in accordance with *Ch 2 Testing Procedures for Metallic Materials*.

3.7.4 The flattening test is to be continued until the interior surfaces of the tube meet.

3.7.5 For the drift expanding test, the mandrel is to have an included angle of 45°.

3.7.6 The results of all mechanical tests are to comply with the appropriate requirements given in *Table 9.3.2 Mechanical properties for acceptance purposes*.

Table 9.3.2 Mechanical properties for acceptance purposes

Designation	0,2% proof stress N/mm^2 minimum	Tensile strength N/mm^2 minimum	Elongation on 5,65 $\sqrt{S_o}$ % minimum	Drift expansion test % minimum	Grain size mm maximum (*see* Note)
Copper-phosphorus deoxidised–non-arsenical	65	220	40	40	–
Copper-phosphorus deoxidised–arsenical	65	220	40	40	–
Aluminium brass	125	320	40	30	0,045
90/10 Copper-nickel-iron	100	270	30	30	0,045
70/30 Copper-nickel-iron	120	360	30	30	0,045
Note When a maximum grain size is specified, the structure is to be completely re-crystallised. The manufacturer is to guarantee the grain size, but testing of each batch will not be required.					

3.7.7 At the discretion of the Surveyor, a modified testing procedure may be adopted for small quantities of materials. In such cases, these may be accepted on the manufacturer's declared chemical composition and hardness tests or other evidence of satisfactory properties.

3.8 Visual examination

3.8.1 All tubes are to be visually examined. The manufacturer is to provide adequate lighting conditions to enable an internal and external examination of the tubes to be carried out.

3.8.2 The inner and outer surfaces are to be clean and smooth but may have a superficial, dull iridescent film on both the inner and outer surfaces.

3.9 Hydraulic test

3.9.1 Each tube is to be subjected to a hydraulic test at the manufacturer's works.

3.9.2 The hydraulic test pressure is to be determined from the following formula, except that the maximum test pressure need not exceed 70 bar:

$$P = \frac{20st}{D}$$

where

P = test pressure, in bar

D = nominal outside diameter, in mm

t = nominal wall thickness, in mm

s = 40 for copper-phosphorous

= 60 for Al-brass and

= 90/10 copper nickel iron

= 75 for 70/30 copper nickel iron

3.9.3 The test pressure is to be maintained for sufficient time to permit proof that the tubes do not weep, leak or undergo a permanent increase in diameter. Unless otherwise agreed, the manufacturer's certificate of satisfactory hydraulic test will be accepted.

3.9.4 Where it is proposed to adopt a test pressure other than that determined in *Ch 9, 3.9 Hydraulic test 3.9.2*, the proposal will be subject to special consideration.

3.9.5 Subject to special approval, an automated eddy current test can be accepted in lieu of the hydraulic test. Discontinuous irregularities on the external and internal surfaces of the tubes are permitted if they are within the agreed dimensional tolerances, with the exception of cracks, which are not permitted.

3.10 Rectification of defects

3.10.1 The repair of defects by welding is not permitted.

3.11 Identification

3.11.1 Tubes are to be clearly marked by the manufacturer in accordance with the requirements of *Ch 1 General Requirements*. The following details are to be shown on all materials which have been accepted:

(a) LR or Lloyd's Register.
(b) Manufacturer's name or trade mark.
(c) Grade of material or designation code.
(d) Identification number and/or initials which will enable the full history of the item to be traced.

3.11.2 Identification is to be by rubber stamp or stencils. Hard stamping is not permitted.

3.12 Certification of materials

3.12.1 A manufacturer's certificate validated by LR is to be issued (*see Ch 1, 3.1 General*), giving the following particulars for each casting or batch of castings which has been accepted:

(a) Purchaser's name and order number.
(b) Specification or grade of material.
(c) Description and dimensions.
(d) Cast number and chemical composition.
(e) Mechanical test results.
(f) Results of stress corrosion cracking test, where applicable.
(g) Hydraulic test report.

■ *Section 1* Anchors

1.1 Scope

1.1.1 This Section makes provision for the manufacture and testing of anchors constructed from cast, forged and fabricated components.

1.1.2 This Section is applicable to the following types of anchor:

(a) Ordinary.
(b) High holding power (HHP).
(c) Super high holding power (SHHP).

1.1.3 In the context of this Section, the reference to swivels refers to those directly attached to the anchor shank in lieu of the conventional 'D' shackle. For other mooring equipment swivels, *see Ch 10, 2.13 Fittings for chain cables*.

1.2 Manufacture

1.2.1 All anchors are to be of an approved design.

1.3 Cast steel anchors

1.3.1 Cast steel anchor heads, shanks, shackles and swivels are to be manufactured and tested in accordance with the requirements of *Ch 4, 1 General requirements* and *Ch 4, 2 Castings for ship and other structural applications*. The Special grade quality is to be used for anchor heads, shanks and shackles.

1.3.2 Special consideration will be given to the use of other grades of steel for the manufacture of swivels.

1.3.3 To confirm the quality of cast anchor components, the Surveyor is to witness drop and hammering tests.

1.3.4 When drop and hammering tests are required, they are to be carried out as follows:

(a) Each anchor, or the components of an anchor made from more than one piece, is to be dropped from a clear height of 4 m onto a steel slab laid on a solid foundation.
(b) Separately cast flukes, shanks and shackles are to be suspended horizontally from a clear height of 4 m before being dropped.
(c) Anchors cast in one piece are to be drop tested twice from a clear height of 4 m. For the first test, the shank and flukes are to be horizontal. For the second test, two steel blocks are to be placed on the slab, arranged so that the middle of each fluke makes contact with the blocks without the crown making contact with the slab, and the orientation of the anchor is to be vertical with the crown nearest the slab.
(d) If the slab is broken by the impact, the test is to be repeated on a new slab.

1.3.5 When hammering tests are required, they are to be carried out after the drop test on each anchor head and shank, which is slung clear of the ground, using a nonmetallic sling, and hammered to check the soundness of the component. A hammer of at least 3 kg mass is to be used.

1.3.6 As part of the manufacturer's works approval, consideration may be given to carrying out drop tests in alternative locations to the manufacturer's when the facilities and location are not suitable.

1.3.7 Repair of fractures or unsoundness detected during the drop or hammering tests are not permitted and the component is to be rejected.

1.4 Forged steel anchors

1.4.1 Forged steel anchor pins, swivels, shanks and shackles are to be manufactured and tested in accordance with the requirements of *Ch 5, 1 General requirements* and *Ch 5, 2 Forgings for ship and other structural applications* carbon and carbon-manganese steel for welded construction. Rolled steel bar may be used provided that the requirements of *Ch 5, 1.2 Manufacture 1.2.9* are met.

1.4.2 Special consideration will be given to other grades of steel for the manufacture of swivels.

1.5 Fabricated steel anchors

1.5.1 Where it is proposed to use plate material for fabricated steel anchors, it is to comply with the requirements of *Ch 3, 2 Normal strength steels for ship and other structural applications* or *Ch 3, 3 Higher strength steels for ship and other structural applications*, and the proposed manufacturing procedure is to be submitted for approval.

1.5.2 Fabricated anchors are to be manufactured in accordance with *Ch 13 Requirements for Welded Construction*.

1.5.3 Stress relief is to be carried out as required in the approved welding procedure.

1.6 Rectification

1.6.1 All rectification is to be agreed with the Surveyor.

1.6.2 Rectification of defective castings is to be carried out in accordance with *Ch 4, 1.9 Rectification and dressing of castings*.

1.6.3 Rectification of defective forgings is to be carried out in accordance with *Ch 5, 1.9 Rectification of defects*.

1.6.4 Rectification of defective fabricated anchors is to be carried out by suitably qualified welders within the parameters of the approved welding procedure used in construction.

1.6.5 Rectification of defective castings, forgings or fabricated anchors by welding is to be carried out using qualified weld procedures in accordance with *Ch 12, 1 General qualification requirements* and *Ch 12, 2 Welding procedure qualification tests for steels*, and in accordance with *Ch 13, 1 General welding requirements* and *Ch 13, 2 Specific requirements for ship hull structure and machinery*.

1.7 Super high holding power (SHHP) anchors

1.7.1 The impact test requirements for SHHP anchor shackles are to be in accordance with the requirements for Grade U3 in *Table 10.2.1 Mechanical properties of finished chain cable and fittings*.

1.8 Assembly

1.8.1 Assembly and fitting is to be carried out in accordance with the approved design.

1.8.2 Securing of anchor pins, shackle pins or swivels by welding is to be carried out by suitably qualified welders in accordance with an approved welding procedure.

1.9 Proof test of anchors

1.9.1 Anchors having a mass of 75 kg or more inclusive of stock (56 kg in the case of high holding power anchors) are to be tested in the presence of the Surveyor at a proving establishment recognised by LR. A list of recognised proving establishments is published separately by LR. In addition to the requirements stated in this Chapter, attention must be given to any relevant statutory requirements of the National Authority of the country in which the ship or mobile offshore unit is to be registered.

1.9.2 The anchor is to be visually examined before application of the proof test load to ensure that it is free from cracks, notches, inclusions and other surface defects that would impair the performance of the product.

1.9.3 As required by *Ch 10, 1.8 Assembly 1.8.1*, each anchor is to be subjected to a proof loading test in an approved testing machine and is to withstand the load given in *Table 10.1.1 Proof load tests for anchors (see Notes 1 and 2)* for the appropriate mass of the anchor. The proof load is to be applied on the arm or on the palm at a spot which, measured from the extremity of the bill, is one-third of the distance between it and the centre of the crown. For stocked anchors, each arm is to be tested individually.

For stockless anchors, both arms are to be tested at the same time, first on one side of the shank, then reversed and tested on the other.

Table 10.1.1 Proof load tests for anchors (*see* Notes 1 and 2)

Mass of anchor (*Ch 10, 1.9 Proof test of anchors 1.9.5*)	Proof test load	Mass of anchor (*Ch 10, 1.9 Proof test of anchors 1.9.5*)	Proof test load	Mass of anchor (*Ch 10, 1.9 Proof test of anchors 1.9.5*)	Proof test load
kg	kN	kg	kN	kg	kN
50	23,2	2200	376,0	7800	861,0
55	25,2	2300	388,0	8000	877,0
60	27,1	2400	401,0	8200	892,0
65	28,9	2500	414,0	8400	908,0
70	30,7	2600	427,0	8600	922,0
75	32,4	2700	438,0	8800	936,0
80	33,9	2800	450,0	9000	949,0
90	36,3	2900	462,0	9200	961,0
100	39,1	3000	474,0	9400	975,0
120	44,3	3100	484,0	9600	987,0
140	49,0	3200	495,0	9800	998,0
160	53,3	3300	506,0	10 000	1010,0
180	57,4	3400	517,0	10 500	1040,0
200	61,3	3500	528,0	11 000	1070,0
225	65,8	3600	537,0	11 500	1090,0
250	70,4	3700	547,0	12 000	1110,0
275	74,9	3800	557,0	12 500	1130,0
300	79,5	3900	567,0	13 000	1160,0
325	84,1	4000	577,0	13 500	1180,0
350	88,8	4100	586,0	14 000	1210,0
375	93,4	4200	595,0	14 500	1230,0
400	97,9	4300	604,0	15 000	1260,0
425	103,0	4400	613,0	15 500	1280,0
450	107,0	4500	622,0	16 000	1300,0
475	112,0	4600	631,0	16 500	1330,0
500	116,0	4700	638,0	17 000	1360,0
550	125,0	4800	645,0	17 500	1390,0
600	132,0	4900	653,0	18 000	1410,0
650	140,0	5000	661,0	18 500	1440,0

700	149,0	5100	669,0	19 000	1470,0
750	158,0	5200	677,0	19 500	1490,0
800	166,0	5300	685,0	20 000	1520,0
850	175,0	5400	691,0	21 000	1570,0
900	182,0	5500	699,0	22 000	1620,0
950	191,0	5600	706,0	23 000	1670,0
1000	199,0	5700	713,0	24 000	1720,0
1050	208,0	5800	721,0	25 000	1770,0
1100	216,0	5900	728,0	26 000	1800,0
1150	224,0	6000	735,0	27 000	1850,0
1200	231,0	6100	740,0	28 000	1900,0
1250	239,0	6200	747,0	29 000	1940,0
1300	247,0	6300	754,0	30 000	1990,0
1350	255,0	6400	760,0	31 000	2030,0
1400	262,0	6500	767,0	32 000	2070,0
1450	270,0	6600	773,0	34 000	2160,0
1500	278,0	6700	779,0	36 000	2250,0
1600	292,0	6800	786,0	38 000	2330,0
1700	307,0	6900	794,0	40 000	2410,0
1800	321,0	7000	804,0	42 000	2490,0
1900	335,0	7200	818,0	44 000	2570,0
2000	349,0	7400	832,0	46 000	2650,0
2100	362,0	7600	845,0	48 000	2730,0

Proof loads for intermediate mass are to be determined by linear interpolation

Note 1. Where ordinary anchors have a mass exceeding 48 000 kg, the proof loads are to be taken as 2,059 (mass of anchor in kg)$^{2/3}$ kN.

Note 2. Where high holding power anchors have a mass exceeding 36 000 kg, the proof loads are to be taken as 2,452 (actual mass of anchor in kg)$^{2/3}$ kN.

1.9.4 The general arrangements for the test are to be such that the complete anchor, including the shackle, shackle pins and any welded or bolted connections are included in the test. If a replacement shackle is needed which requires welding or heating for fitting, the combined anchor and shackle are to be proof load tested. If welding or heating is not involved in fitting, the shackle may be proof load tested separately from the anchor.

1.9.5 The mass to be used in *Table 10.1.1 Proof load tests for anchors (see Notes 1 and 2)* is:

(a) For stockless anchors, the total mass of the anchor.
(b) For stocked anchors, the mass of the anchor excluding the stock.
(c) For high holding power anchors, a nominal mass equal to 1,33 times the actual total mass of the anchor.
(d) For mooring anchors, including positional mooring anchors, a nominal mass equal to 1,33 times the actual total mass of the anchor, unless specifically agreed otherwise.
(e) For super high holding power anchors, a nominal mass equal to twice the actual total mass of the anchor.

1.9.6 For positional mooring anchors, the proof test loading is to be that required by *Ch 10, 1.9 Proof test of anchors 1.9.3* or 50 per cent of the minimum break strength of the intended anchor line, whichever is the greater.

1.9.7 The gauge length is to be measured with 10 per cent of the required load applied, before and after proof test. The two measurements shall differ by no more than 1 per cent. The gauge length is the distance between the tip of each fluke and a point on the shank adjacent to the shackle pin, *see Figure 10.1.1 Location of gauge length measurement during proof load*.

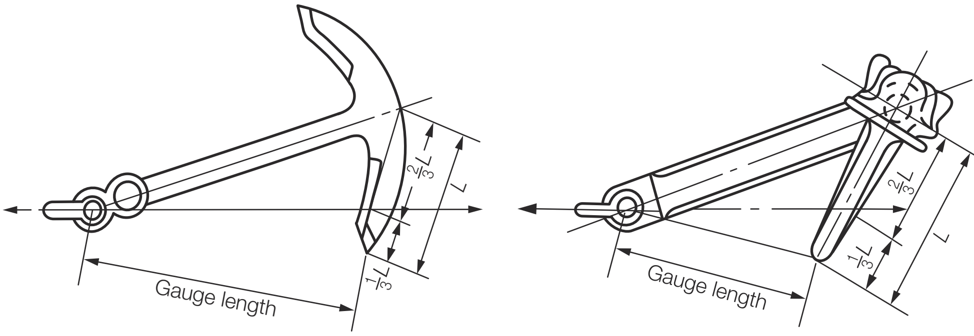


Figure 10.1.1 Location of gauge length measurement during proof load

1.9.8 After proof testing, all accessible surfaces are to be visually inspected by the Surveyor.

1.9.9 Following proof testing, NDE is to be conducted as described in *Table 10.1.2 NDE requirements following proof testing for Ordinary and HHP anchors* for ordinary and HHP anchors and *Table 10.1.3 NDE requirements following proof testing for SHHP anchors* for SHHP anchors.

Table 10.1.2 NDE requirements following proof testing for Ordinary and HHP anchors

Location	Method of NDE
Feeder heads, runners and risers of castings	Magnetic particle inspection and ultrasonic test, *see* Note 1
All welds	Magnetic particle inspection
Forged components	Not required
Fabrication welds	Magnetic particle inspection
Note 1. *See also Ch 10, 1.9 Proof test of anchors 1.9.10*. Note 2. Penetrant testing is to be used in lieu of magnetic particle testing for stainless steel, aluminium and copper alloy anchors.	

Table 10.1.3 NDE requirements following proof testing for SHHP anchors

Location	Method of NDE
Feeder heads, runners and risers of castings	Magnetic particle inspection and ultrasonic test, *see* Note 1
All surfaces of castings	Magnetic particle inspection
All welds	Magnetic particle inspection
Forged components	Not required

Fabrication welds	Magnetic particle inspection
Note 1. *See also Ch 10, 1.9 Proof test of anchors 1.9.10*.	
Note 2. Additionally, all surfaces of all SHHP anchors are to be surface inspected by the magnetic particle or penetrant method as appropriate.	
Note 3. Penetrant is to be used in lieu of magnetic particle testing for stainless steel, aluminium and copper alloy anchors.	

1.9.10 Each casting is to be subjected to ultrasonic inspection in the region of runners and risers, or where excess material has been removed by thermal methods. This examination is to extend around the whole periphery of the casting and for a distance of t/3 beyond the area affected, where t is the maximum thickness. In addition, random areas are to be selected by the Surveyor and examined.

1.9.11 Acceptance criteria for castings are to be in accordance with *Ch 4 Steel Castings*.

1.9.12 Acceptance criteria for forgings are to be in accordance with *Ch 5 Steel Forgings*.

1.9.13 Paint or anti-corrosive coatings are not to be applied until these inspections are completed to the satisfaction of the Surveyor.

1.9.14 On completion of the proof testing, anchors made in more than one piece are to be examined for free movement of their heads over the complete range of rotation.

1.10 Clearances and tolerances

1.10.1 Where no fitting tolerances are specified on the approved plans the following assembly and fitting tolerance are to be applied.

1.10.2 The clearance either side of the shank within the shackle jaws and the shackle pin in the shank end hole is to be no more than 3 mm for small anchors up to 3 tonnes, 4 mm for anchors up to 5 tonnes, 6 mm for anchors up to 7 tonnes and is not to exceed 12 mm for larger anchors.

1.10.3 The shackle pin to hole tolerance is to be no more than 0,5 mm for pins up to 57 mm and 1,0 mm for pins of larger diameter and the eyes of the shackle are to be chamfered on the outside to ensure a good tightness when the pin is fitted. The shackle pin is to mate with the shackle such that it can be inserted with moderate hand pressure, allowing disassembly if required.

1.10.4 The trunnion pin is to fit within the chamber such that it will achieve the closest fit which can be carried out by hand. The pin is to be long enough to prevent horizontal movement. The gap is to be no more than 1 per cent of the chamber length.

1.10.5 The lateral movement of the shank is not to exceed 3 degrees from the centreline datum, *see Figure 10.1.2 Allowable lateral movement of shank*.

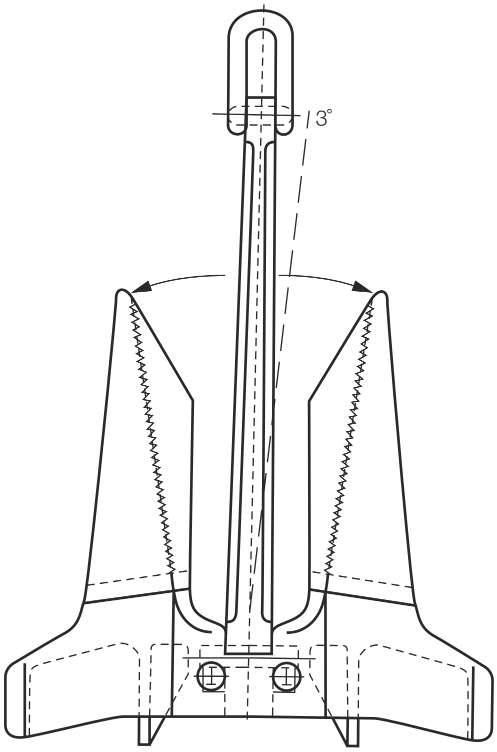


Figure 10.1.2 Allowable lateral movement of shank

1.10.6 Unless otherwise agreed, the verification of mass and dimensions is the responsibility of the manufacturer. The Surveyor is only required to monitor this inspection. The mass of the anchor is to exclude the mass of the swivel, unless the swivel is in lieu of the conventional 'D' shackle.

1.11 Identification

1.11.1 Identification marks on the shank are to be approximately level with the fluke tips. On the fluke, these markings are to be approximately at a distance of two thirds from the tip of the bill to the centre line of the crown on the right hand fluke, looking from the crown towards the shank.

1.11.2 The following details are to be shown on all anchors:

(a) LR or Lloyd's Register and abbreviated name of LR's local office issuing the certificate.
(b) Number of the certificate.
(c) Month and year of test.
(d) Mass (also the letters `HHP' when approved as high holding power anchors or 'SHHP' when approved as super high holding power anchors).
(e) Mass of stock (in the case of stocked anchors).
(f) National Authority requirements, as applicable.
(g) Manufacturer's mark.

1.11.3 In addition to *Ch 10, 1.11 Identification 1.11.2*, each important part of an anchor is to be plainly marked by the maker with the words `forged steel' or `cast steel' as appropriate. Fabricated steel anchor heads do not require special marking.

1.12 Certification

1.12.1 The manufacturer is to provide the Surveyor with a written statement that the anchor has been manufactured and tested in accordance with LR Rules together with the following particulars:

(a) Purchaser`s name and order number.
(b) Type of anchor and principal dimensions.

(c) Mass of anchor.
(d) Identification mark which will enable the full history of manufacture to be traced.
(e) Chemical composition.
(f) Details of heat treatment.
(g) Mechanical test results.
(h) Proof load.
(i) Results of the non-destrucive examination.
(j) Weld location maps (cast steel anchors only).

1.12.2 Shanks, heads, pins, shackles and swivels are to be certified by LR in accordance with the relevant sections of Chapters *Ch 3 Rolled Steel Plates, Strip, Sections and Bars*, *Ch 4 Steel Castings* and *Ch 5 Steel Forgings*.

1.12.3 An LR Anchor Certificate is to be issued for the completed anchor which will include the following particulars:

(a) Manufacturer's name.
(b) Type of anchor.
(c) Mass of anchor.
(d) Grade of materials.
(e) Proof test load.
(f) Heat treatment.
(g) Marking applied to anchor.
(h) Dimensions.
(i) General Approval of an Anchor Design Certificate Number.
(j) Fluke and shank identification numbers.

■ *Section 2* Stud link chain cables for ships

2.1 Scope

2.1.1 Provision is made in this Section for a range of grades, U1, U2 and U3, of stud link chain and fittings intended for anchor cables for ships.

2.1.2 The requirements for mooring chain cables are given in *Ch 10, 3 Stud link mooring chain cables*.

2.1.3 The design of chain cables is to be to a Standard recognised by LR, such as ISO 1704.

2.2 Manufacture

2.2.1 All grades of chain cable and accessories are to be manufactured by approved procedures at works approved by LR. A list of approved manufacturers of stud link chain cables and fittings is published separately by LR.

2.2.2 The links may be made by the flash-butt or other approved welding process, or in the case of Grades U2 and U3 they may be flash-butt welded or drop forged, designated U2(a) or U3(a), or cast steel designated U2(b) or U3(b), *see Table 10.2.5 Number of breaking tests from completed cables*.

2.2.3 As far as practicable, consecutive links in all chain cable should originate from a single cast or batch of bar stock (*see Ch 3, 9.6 Mechanical tests 9.6.1*), and indicating marks should be stamped on the final link formed from one cast or batch and the first link formed from a separate cast or batch.

2.2.4 A length of chain cable is to measure not more than 27,5m and is to comprise an odd number of links. In this context, a length is a statutory term and is the basis for the number of test samples.

2.2.5 Where end links or enlarged links are manufactured and heat treated as part of and at the same time as the chain cable and are of the same cast heat of steel, they may be excluded from separate mechanical tests and break load tests.

2.3 Flash butt welded chain cable

2.3.1 Bar material is to comply with the requirements of *Ch 3, 9 Bars for welded chain cables* and may be heated either by electrical resistance or in a furnace. For electrical resistance heating, the process is to be controlled by an optical heat sensor. For

furnace heating, thermocouples in close proximity to the bars are to be used for control. The temperature is to be continuously recorded. In both cases, the controls are to be checked at least once every eight hours and checks are to be recorded.

2.3.2 Mechanical properties testing of U1 cable is not required. For Grade U2 cable supplied in the as-welded condition, and Grade U3 in all conditions, one tensile and one set of three Charpy V-notch impact test specimens are to be taken at the side of a link opposite the weld from at least every fourth 27,5m length of cable. A further set of three impact test specimens is to be taken with the notch positioned at the centre of the weld, *see Table 10.2.3 Condition of supply and scope of mechanical tests for finished chain cables and fittings*. The test specimens are not to be selected from the same length as that from which the breaking test sample is taken, unless breaking test samples are to be taken from every length of the batch. All test samples are to be correctly identified with the lengths of cable represented.

2.3.3 The test links from which the mechanical test specimens are prepared are to be made as part of the chain cable and are to be heat treated with it. They may be removed from the cable prior to heat treatment provided that each sample is heat treated with, and in the same manner as, the chain it represents prior to preparation of the mechanical test specimens.

2.3.4 The results of tests on specimens taken from the non-welded areas are to comply with the appropriate requirements of *Table 10.2.1 Mechanical properties of finished chain cable and fittings*. The results of tests on the welds are to comply with the requirements of *Table 10.2.6 Mechanical properties of welds in chain cables*.

2.4 Cast chain cables

2.4.1 The manufacture of cast steel chain cable is generally to be in accordance with the requirements of *Ch 4, 1 General requirements*, as appropriate.

2.4.2 The chemical composition of ladle samples is to comply with the specification approved by LR.

2.4.3 Separately cast test samples are to be provided from each cast. They are to be of similar dimensions to the links they represent and are to be heat treated together with, and in the same manner as, the completed chain cable, *see Table 10.2.3 Condition of supply and scope of mechanical tests for finished chain cables and fittings*.

2.4.4 Tensile and Charpy V-notch impact test specimens are to be taken from each test sample and machined to the dimensions given in *Ch 2, 3 Impact tests*.

2.4.5 The results of all tests are to comply with the requirements given in *Table 10.2.1 Mechanical properties of finished chain cable and fittings* for the relevant grade.

2.5 Forged chain cables

2.5.1 The procedure for the manufacture and testing of drop forgings for chain cable will be specially considered, but is generally to be in accordance with the appropriate requirements of *Ch 5, 1 General requirements*.

2.5.2 The chemical composition is to comply with *Table 10.2.2 Chemical composition of butt welded and forged chain cable*.

2.5.3 The completed forgings are to be heat treated in accordance with *Ch 10, 2.3 Flash butt welded chain cable*.

2.5.4 Test samples are to be provided in the form of forgings of similar dimensions to the links they represent. These test samples are to be from the same steel-making heat and heat treated together with the links they represent.

2.5.5 One tensile and three Charpy V-notch specimens are to be taken from each test sample.

2.5.6 The results of mechanical tests are to comply with the requirements of *Table 10.2.1 Mechanical properties of finished chain cable and fittings* for the relevant grade.

Table 10.2.1 Mechanical properties of finished chain cable and fittings

Grade	Yield stress N/mm^2 minimum	Tensile strength N/mm^2	Elongation on 5,65 $\sqrt{S_0}$ % minimum	Reduction of area % minimum	Charpy V-notch impact tests	
					Test temperature °C	Average energy J minimum
U2	295	490 – 690	22	—	0 (*see* Note 1)	27
U3	410	690 minimum	17	40	0	60

					–20 (*see* Note 2)	35

Note 1. When required *see Table 10.2.3 Condition of supply and scope of mechanical tests for finished chain cables and fittings*.

Note 2. Testing may be carried out at either 0°C or –20°C.

Note 3. Mechanical testing is not required for finished chain cables and fittings in Grade U1.

Table 10.2.2 Chemical composition of butt welded and forged chain cable

Grade	Chemical composition %												
	C max.	Si	Mn	P max.	S max.	Al	N max.	Cr max.	Cu max.	Nb max.	Ni max.	V max.	Mo max.
U1	0,20	0,15 – 0,35	0,40 min.	0,04	0,04	—	—	—	—	—	—	—	—
U2	0,24	0,15 – 0,55	1,60 max.	0,035	0,035	0,02 min. *see* Note 1	—	—	—	—	—	—	—
U3	0,33	0,15 – 0,35	1,90 max.	0,04	0,04	0,065 max. *see* Note 2	0,015	0,25	0,35	0,05 *see* Note 2	0,40	0,10 *see* Note 2	0,08

Note 1. Aluminium may be partly replaced by other grain refining elements.

Note 2. To obtain fine grain steel, at least one of these grain refining elements must be present in sufficient amount.

Table 10.2.3 Condition of supply and scope of mechanical tests for finished chain cables and fittings

Grade	Manufacturing method	Condition of supply	Number of test specimens on every four lengths of chain cable of 27,5 m or less, or on each batch of fittings		
			Tensile test on base materials	Charpy V-notch impact test	
				Base material	Weldment
U1 cable	Flash butt welded	As welded Normalised	— —	— —	— —
U2 cable	Flash butt welded	As welded Normalised	1 —	3 —	3 —
U3 cable	Flash butt welded	Normalised Normalised and Tempered Quenched and Tempered	1	3	3
U2 cable	Cast or drop forged	Normalised	1	3	—
U3 cable	Cast or drop forged	Normalised Normalised and Tempered Quenched and Tempered	1	3	—
U2 fittings	Cast or drop forged	Normalised	1	3	—

U3 fittings	Cast or drop forged	Normalised Normalised and Tempered Quenched and Tempered	1	3	—

2.6 Stud material

2.6.1 Steel studs are to be used for all grades of welded chain cable. In general, the carbon content should not exceed 0,23 per cent but mechanical tests for acceptance purposes are not required.

2.7 Welding of studs

2.7.1 Where studs are welded into the links this is to be completed before the chain cable is heat treated.

2.7.2 The stud ends must be a good fit inside the link, and the weld is to be confined to the stud end opposite the flash-butt weld. The full periphery of the stud end is to be welded. If, however, it can be demonstrated to the Surveyor that the quality of welding is of a high standard then partial peripheral welding may be accepted provided that welds are made only at the sides of the stud and that each run extends continuously for at least 25 per cent of the stud periphery. Weld start/stop positions are not to be located in the plane of the chain cable.

2.7.3 The welds are to be made by qualified welders using an approved procedure and consumables approved to Grade 3 and low hydrogen, in accordance with *Ch 11 Approval of Welding Consumables*.

2.7.4 The welds are to be of good quality and free from defects liable to impair the proper use of the chain. Undercuts, end craters and similar stress raising defects shall, where necessary, be ground off.

2.7.5 At least one stud weld within each length of cable is to be inspected using dye penetrant testing in accordance with *Ch 1, 5 Non-destructive examination* after the chain has been proof loaded. If a crack is found, the stud welds in the adjoining links are to be inspected; if a crack is found in either link, all the stud welds in that length are to be inspected using dye penetrant.

2.8 Heat treatment of completed chain cables

2.8.1 The completed chain cable is to be heat treated in accordance with *Table 10.2.3 Condition of supply and scope of mechanical tests for finished chain cables and fittings* for the appropriate grade of cable.

2.8.2 Special consideration will be given to the heat treatment of certain types of drop forged chain cable.

2.8.3 In all cases, heat treatment is to be carried out prior to the proof loading and breaking tests.

2.8.4 All test samples are to be heat treated with, and in the same way as, the chain cables they represent.

2.9 Testing of completed chain cables

2.9.1 All chain cables are to be subjected to a Proof Load test and a Breaking Load test. In addition, mechanical tests should be carried out where required, *see Table 10.2.3 Condition of supply and scope of mechanical tests for finished chain cables and fittings*.

2.9.2 All chain cables are to be tested in the presence of a Surveyor, at a proving establishment recognised by LR. A list of recognised proving establishments is published separately by LR. In addition to the requirements stated in this Chapter, attention must be given to any relevant statutory requirements of the National Authority of the country in which the ship is to be registered.

2.10 Proof load tests

2.10.1 Each length of chain cable is to be subjected to a proof loading test in an approved testing machine and is to withstand the load given in *Table 10.2.4 Test loads for stud link anchor chain cables* for the appropriate grade and size of cable.

Table 10.2.4 Test loads for stud link anchor chain cables

Chain diameter d mm	Grade U1		Grade U2		Grade U3	
	Proof load kN $0,00686d^{2}(44–0,08d)$	Breaking load kN $0,00981d^{2}(44–0,08d)$	Proof load kN $0,00981d^{2}(44–0,08d)$	Breaking load kN $0,01373d^{2}(44–0,08d)$	Proof load kN $0,01373d^{2}(44–0,08d)$	Breaking load kN $0,01961d^{2}(44–0,08d)$
12,5	46	66	66	92	92	132
14	58	82	82	115	115	165

16	75	107	107	150	150	214
17,5	89	128	128	179	179	256
19	105	150	150	211	211	301
20,5	122	175	175	244	244	349
22	140	201	201	281	281	401
24	166	238	238	333	333	475
26	194	278	278	389	389	556
28	225	321	321	450	450	642
30	257	367	367	514	514	734
32	291	416	416	583	583	832
34	327	468	468	655	655	936
36	366	523	523	732	732	1045
38	406	580	580	812	812	1160
40	448	640	640	896	896	1280
42	492	703	703	984	984	1406
44	538	769	769	1076	1076	1537
46	585	837	837	1171	1171	1673
48	635	908	908	1270	1270	1814
50	686	981	981	1373	1373	1961
52	739	1057	1057	1479	1479	2113
54	794	1135	1135	1589	1589	2269
56	850	1216	1216	1702	1702	2430
58	908	1299	1299	1818	1818	2597
60	968	1384	1384	1938	1938	2767
62	1029	1472	1472	2060	2060	2943
64	1092	1562	1562	2187	2187	3123
66	1157	1655	1655	2316	2316	3308
68	1223	1749	1749	2448	2448	3496
70	1291	1846	1846	2583	2583	3690
73	1395	1995	1995	2792	2792	3988
76	1503	2149	2149	3007	3007	4295
78	1576	2254	2254	3154	3154	4505
81	1689	2415	2415	3380	3380	4827
84	1805	2580	2580	3612	3612	5158
87	1923	2750	2750	3849	3849	5498

90	2045	2924	2924	4093	4093	5845
92	2127	3042	3042	4258	4258	6081
95	2254	3223	3223	4510	4510	6442
97	2339	3345	3345	4682	4682	6687
100	2470	3532	3532	4943	4943	7060
102	2558	3658	3658	5120	5120	7312
105	2692	3850	3850	5389	5389	7697
107	2783	3980	3980	5571	5571	7957
111	2968	4245	4245	5941	5941	8486
114	3110	4447	4447	6224	6224	8889
117	3253	4652	4652	6511	6511	9299
120	3398	4859	4859	6801	6801	9714
122	3496	4999	4999	6997	6997	9994
124	3595	5141	5141	7195	7195	10276
127	3744	5354	5354	7494	7494	10703
130	3895	5571	5571	7796	7796	11135
132	3997	5716	5716	8000	8000	11426
137	4254	6083	6083	8514	8514	12161
142	4515	6456	6456	9036	9036	12906
147	4779	6834	6834	9565	9565	13662
152	5046	7217	7217	10100	10100	14426
157	5316	7602	7602	10640	10640	15197
162	5588	7991	7991	11185	11185	15975

2.10.2 On completion of the test, each link is to be visually examined and is to be free from significant defects. Special attention is to be given to welds.

2.10.3 Should any link be found to be defective it is to be replaced by an approved connecting link (joining shackle or substitute link as detailed in *Ch 10, 2.14 Substitute single links*). The chain is then to be subjected to a repeat of the proof load test followed by re-examination.

2.10.4 If a link breaks during proof load testing, a sample consisting of three common links is to be taken from each side of the broken link and subjected to a breaking test as detailed in *Ch 10, 2.12 Breaking load tests*. If either of these samples fails, the length of cable is not to be accepted. A thorough examination of all broken links is to be made to determine the cause of failure and, after evaluation, LR will consider the extent of cable which is to be rejected.

2.11 Dimensional inspection

2.11.1 The measurement of dimensions in *Ch 10, 2.11 Dimensional inspection 2.11.2* and *Ch 10, 2.11 Dimensional inspection 2.11.3* is to take place after the proof load has been applied to the chain and subsequently reduced to the load of 10 per cent of the proof load. All other dimensional checks are to be carried out without application of load.

2.11.2 On every 27,5 m length of chain, five links are to be selected for measurement of length to ensure that the maximum allowable tolerance on a length of five links is plus 2,5 per cent. No under-tolerance is permitted.

2.11.3 If a five-link length of chain exceeds the tolerance given in *Ch 10, 2.11 Dimensional inspection 2.11.2*, then the entire chain is to be checked for length, five links at a time with an overlap of two links, which is to include the first five links. Oversize links are to be removed and an approved connecting link inserted.

2.11.4 Checks of all other dimensions are to be made on three links from every four 27,5 m lengths. All measurements are to be made on links selected by the Surveyor and are to be carried out to the Surveyor's satisfaction.

2.11.5 If one of the links detailed in *Ch 10, 2.11 Dimensional inspection 2.11.4* fails to comply with the required tolerances, measurements are to be made on all four 27,5 m lengths.

2.11.6 If more than one link in a 27,5 m length of chain cable fails to meet the tolerance requirements, all the links in that length are to be measured.

2.11.7 Links that fail to comply with tolerance requirements are to be removed and approved connecting links inserted. Where a significant number of links fail to comply with the tolerance requirements the chain is to be rejected.

2.11.8 The form and proportion of links and shackles are to be in accordance with a standard recognised by LR, such as ISO 1704; alternatively, the design may be specifically approved by LR.

2.11.9 Manufacturing tolerances on stud link chain are to be within ±2,5 per cent (taking into account that all components of the chain are to be a good fit with one another), except for those detailed in *Ch 10, 2.11 Dimensional inspection 2.11.10*.

2.11.10 The nominal diameter, d, is to be the average of the diameters, measured in the plane of the link, d_{c}, and perpendicular to the plane of the link, d_{p}, *see Figure 10.2.2 Common link*. The negative tolerance on the nominal diameter is not to exceed the following:

(a) Minus 1 mm when $d \leq 40$ mm
(b) Minus 2 mm when 40 mm $< d \leq 84$ mm
(c) Minus 3 mm when 84 mm $< d \leq 122$ mm
(d) Minus 4 mm when $d > 122$ mm

For diameters of 20mm or greater, the plus tolerance on the diameter at the crown measured perpendicular to the plane of the link, d_{p}, is not to exceed 5 per cent. For diameters less than 20mm, the plus tolerance is to be agreed between the chain manufacturer and bar material supplier.

2.11.11 The cross-sectional area is to be calculated using the nominal diameter, d. The cross-sectional area at the crown of the link is to have no negative tolerance.

2.11.12 The diameter measured at locations other than the crown is to have no negative tolerance. For diameters of 20mm or greater, the plus tolerance may be up to 5 percent of the nominal diameter except at the butt weld where it is to be in accordance with the manufacturer's specification, which is to be agreed by LR. For diameters less than 20mm, the plus tolerance is to be agreed between the chain manufacturer and bar material supplier.

2.11.13 Studs must be located in the links centrally and at right angles to the sides of the link, although the studs at each end of any length may also be located off-centre to facilitate the insertion of the joining shackle. The following tolerances in *Figure 10.2.1 Manufacturing tolerances* will be accepted provided that the stud fits snugly and its ends lie practically flush against the inside of the link:

(a) Maximum off-centre distance 'X': 10 per cent of the nominal diameter d
(b) Maximum deviation 'α' from the 90° – position: 4°.

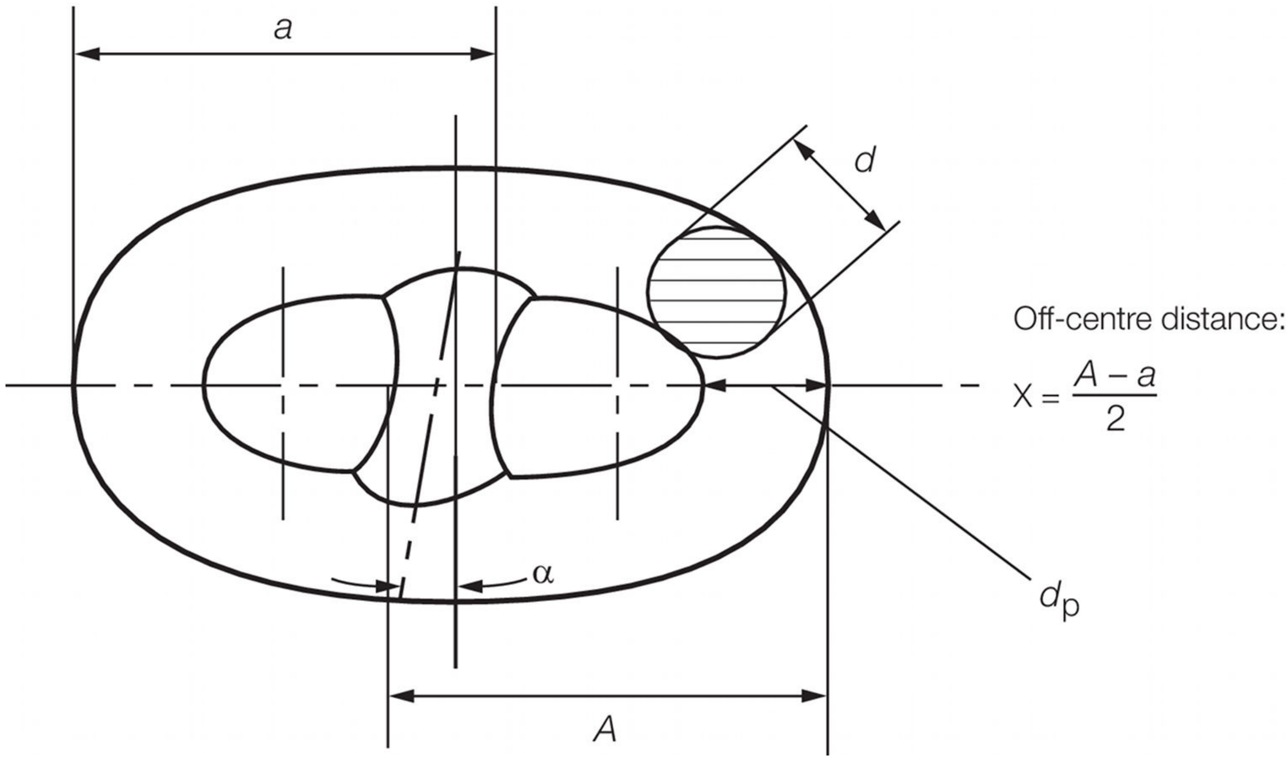


Figure 10.2.1 Manufacturing tolerances

2.11.14 All individual parts must have a clean surface consistent with the method of manufacture and the surface is to be free from cracks, notches, inclusions and other defects which could impair the performance of the product. Crack-like imperfections less than 3 mm in length can be ignored. The flash produced by upsetting or drop forging must be properly removed.

2.11.15 Minor surface imperfections may be ground off so as to leave a gentle transition to the surrounding surface provided that the cross-sectional area remains equal to or greater than the nominal cross-sectional area. Remote from the crown, local grinding up to 5 per cent of the nominal diameter may be permitted.

2.11.16 Paint or anti-corrosive coatings are not to be applied until these inspections are completed to the satisfaction of the Surveyor.

2.12 Breaking load tests

2.12.1 Breaking load tests are to be carried out on three-link samples selected by the Surveyor from the completed (including heat treatment) chain. The test links may be removed from the chain prior to heat treatment provided that each sample is heat treated with, and in the same manner as the chain it represents. They are to be properly identified with the lengths of chain they represent.

2.12.2 The number of tests required is to be in accordance with *Table 10.2.5 Number of breaking tests from completed cables* except that for chafing chain for Emergency Towing Arrangements (ETA), *see Pt 3, Ch 13, 10.2 Chafing chain and wire or fibre rope for Emergency Towing Arrangements*, one test is to be carried out on each 110 m of finished chains.

2.12.3 Breaking test specimens are to withstand the load given in *Table 10.2.4 Test loads for stud link anchor chain cables* for the appropriate grade and size of cable. The specimen is considered to have passed this test if it has shown no sign of fracture after application of the required load for a minimum of 30 seconds.

Table 10.2.5 Number of breaking tests from completed cables

Designation		Method of manufacture	Number of breaking test specimens
Grade	U1	Flash-butt welded and heat treated	One from every four lengths of 27,5 m or less
Grade	U2(a) U3(a)	Flash-butt welded, or drop forged and heat treated	One from every four lengths of 27,5 m or less
Grade	U1 U2(a)	Flash-butt welded but not heat treated	One from each length of 27,5 m or less
Grade	U2(b) U3(b)	Cast and heat treated	One per heat treatment batch with a minimum of one from every four lengths of 27,5 m or less

Table 10.2.6 Mechanical properties of welds in chain cables

Grade	Charpy V-notch impact test	
	Test temperature °C	Average energy J min
U1	–	–
U2	0 (*see* Note 1)	27
U3	0	50
	–20 (*see* Note 2)	27
Note 1. Impact tests are only required if the chain cable is not heat treated.		
Note 2. Impact testing may be carried out at 0°C or minus 20°C.		

2.12.4 Where a breaking test specimen fails, a further specimen is to be cut from the same length of cable and subjected to test. If this re-test fails, the length of cable from which it was taken is to be rejected. When this test is also representative of other lengths, each of the remaining lengths is to be individually tested by taking a breaking test specimen from each length of the batch. If one of these further tests fails, the entire set of lengths represented by the original test is to be rejected.

2.12.5 For large diameter cables where the required breaking load is greater than the capacity of the testing machines, special consideration will be given to acceptance of an alternative testing procedure.

2.13 Fittings for chain cables

2.13.1 Cable fittings are to be manufactured at an approved works.

2.13.2 The materials from which the fittings are made are to be manufactured at approved works, in accordance with the appropriate requirements of *Ch 4, 1 General requirements* or *Ch 5, 1 General requirements* respectively. Alternative arrangements may be agreed provided that full details concerning the manufacturer are submitted to LR.

2.13.3 All fittings are to be manufactured to an approved manufacturing specification, and provision is to be made for tensile specimens and, where applicable, impact test specimens, *see Table 10.2.3 Condition of supply and scope of mechanical tests for finished chain cables and fittings*. The mechanical test requirements are the same as those for the relevant grade of chain cable, *see Table 10.2.1 Mechanical properties of finished chain cable and fittings*.

2.13.4 The test samples are to be prepared in accordance with *Ch 10, 2.4 Cast chain cables 2.4.3* or *Ch 10, 2.5 Forged chain cables 2.5.4* as applicable. The test specimens are to be subjected to heat treatment with the fittings they represent.

2.13.5 For mechanical testing, a batch is defined as fittings of the same grade, size and heat treatment furnace load and is to have originated from a single cast heat of steel.

2.13.6 Mechanical tests of pins are to be taken in accordance with *Ch 10, 3.8 Fittings for offshore mooring chain 3.8.15*.

2.13.7 Fittings such as shackles, swivels and swivel shackles are to be forged or cast in steel of at least Grade U2. The welded construction of fittings may also be approved providing that full details of the manufacturing process and the heat treatment are submitted.

2.13.8 All chain cable accessories, including spares, are to be subjected to the proof loads appropriate to the grade and size of cable for which they are intended. These include shackles, swivels, swivel shackles, enlarged links and end links. Anchor shackles, however, are to be tested in combination with the anchor, *see Ch 10, 1.4 Forged steel anchors*.

2.13.9 The appropriate breaking load is to be applied for a minimum of 30 seconds to at least one item out of every batch of up to 25 detachable links, shackles, swivels, swivel shackles, enlarged end links and end links and at least one item out of every batch of up to 50 for lugless (Kenter) shackles. The item tested is to be destroyed and not used as part of an outfit. For the purposes of break load testing, a batch of accessories is to consist of:

(a) the same accessory type, grade and size;
(b) the same rolling or forging or casting process; and
(c) accessories that are heat treated together in the same furnace.

2.13.10 Where a break load batch as defined in *Ch 10, 2.13 Fittings for chain cables 2.13.9* requires a normalise or normalise and temper heat treatment, the size of accessories may vary within a batch provided that the heat treatment cycle is chosen to satisfy the accessory with the largest cross-section size. The batch may consist of more than one steel-making heat provided that the two accessories are break tested, one with the largest crosssection size and one with the smallest cross-section size.

2.13.11 Where a break load batch as defined in *Ch 10, 2.13 Fittings for chain cables 2.13.9* requires a quench and temper heat treatment, the size of the accessories within the batch is to be the same and is limited to the same steel-making heat.

2.13.12 If the sample fails to withstand the breaking load without fracture, two more samples from the same batch may be tested. If either of these samples fails, the batch is to be rejected.

2.13.13 Fittings of increased dimensions or higher grade material may be used subject to approval by LR.

2.13.14 Where items of increased dimensions are used or if material of a higher grade than is specified is used, the breaking load is to be applied to each item, and the items so tested included with the outfit. For the purpose of this paragraph, items of increased dimensions are those so designed that their breaking strength is not less than 1,4 times the Rule minimum breaking load of the chain cable with which they are to be used.

2.13.15 LR may waive the breaking load test provided that:

(a) the breaking load test has been completed satisfactorily during approval testing, and
(b) the tensile and impact properties of each manufacturing batch are proved and
(c) the accessories are subjected to suitable non-destructive testing.

2.13.16 All testing is to be carried out in the presence of the Surveyor and to his satisfaction.

2.13.17 The following tolerances are applicable to accessories:

(a) Nominal diameter: plus 5 per cent, minus 0 per cent
(b) Other dimensions: ±2,5 per cent
(c) The radii of all machined corners are to be not less than 0,03 times the nominal chain diameter

2.13.18 All fittings are to be stamped in accordance with *Ch 10, 2.15 Identification*.

2.14 Substitute single links

2.14.1 Single links to connect lengths of chain cable or to substitute for defective links, without the necessity for re-heat treatment of the whole cable length, are to be made by the chain manufacturer in accordance with an approved procedure. Separate approvals are required for each grade of chain cable and the tests are to be made on the maximum size of chain for which approval is sought. Re-approval is required annually.

2.14.2 Manufacture and heat treatment of the substitute link are not to affect the strength of the adjoining links. The temperature reached by these links is nowhere to exceed 250°C.

2.14.3 The steel bar used is to conform with the specification for the chain in accordance with *Ch 3, 9 Bars for welded chain cables*.

2.14.4 Details of the method of manufacture, including heat treatment, are to be submitted for approval, together with the results of a series of tests laid down by LR.

2.14.5 All links involved in the approval tests are to be destroyed and are not to be used as part of a chain cable.

2.14.6 Every substitute link included in a chain cable is to be subjected to the proof load appropriate to the grade and size of chain in which it is incorporated, as detailed in *Table 10.2.6 Mechanical properties of welds in chain cables*.

2.14.7 Each substitute link is to be stamped on the stud with the identification marks listed in *Ch 10, 2.15 Identification 2.15.1* plus a unique number for the link. The adjoining links are also to be stamped on the studs.

2.15 Identification

2.15.1 All lengths of Grades U1, U2 and U3 cable and all fittings are to be stamped with the following identification marks:

(a) LR or Lloyd's Register and abbreviated name of LR's local office issuing the certificate.
(b) Number of certificate.
(c) Proof load and grade of chain.
(d) Surveyor's personal stamp.
(e) Each length of chain cable is to be stamped on both ends.

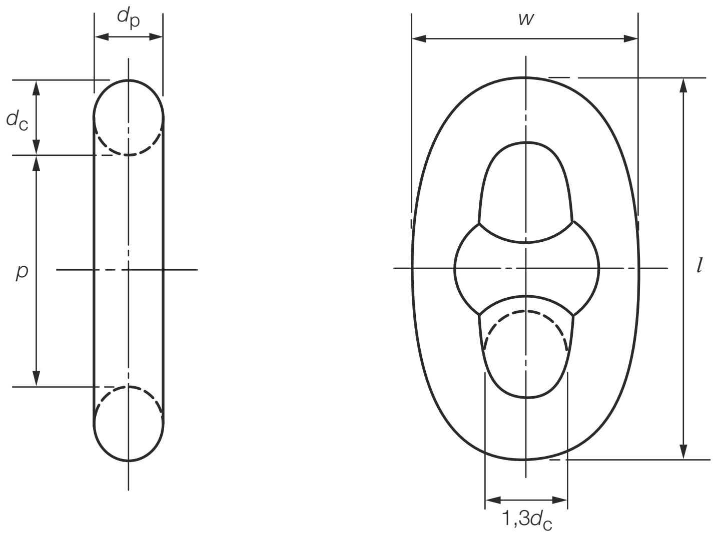
2.16 Certification

2.16.1 An LR certificate is to be issued for chain cable only, fittings only or chain cable with associated fittings.

2.16.2 Each test certificate is to include the following particulars for all items included on the certificate:

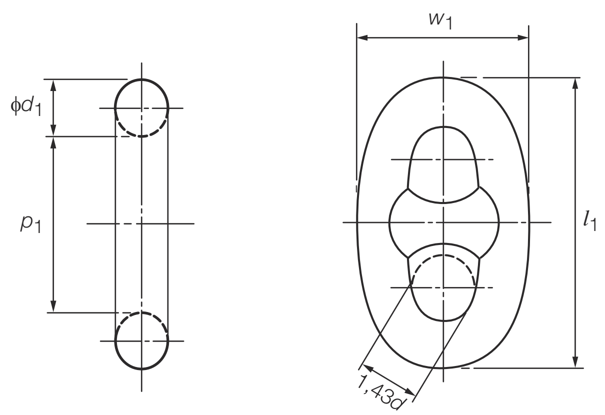
(a) Manufacturer's name.
(b) Purchaser's name and order number.
(c) Description and dimensions.
(d) Grade of chain cable.
(e) Identification mark which will enable the full history of the chain or fitting to be traced.
(f) Chemical composition.
(g) Details of heat treatment.
(h) Mechanical test results.
(i) Breaking test load.
(j) Proof load.

2.16.3 Where appropriate, the certificate is to include a list of all substitute links together with their grade of steel, the name of the steelmaker, the heat number and the purchase order number.



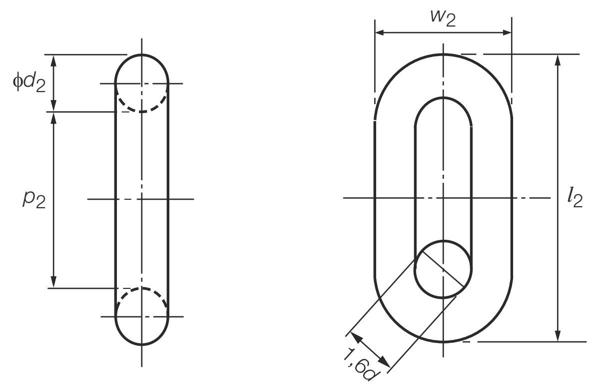
d = nominal diameter $\left(\frac{d_c + d_p}{2}\right)$
d_c = nominal diameter at crown measured in plane of link
d_p = nominal diameter at crown measured perpendicular to plane of link
l = 6d_c
p = 4d_c
w = 3,6d_c to the nearest millimetre

Figure 10.2.2 Common link



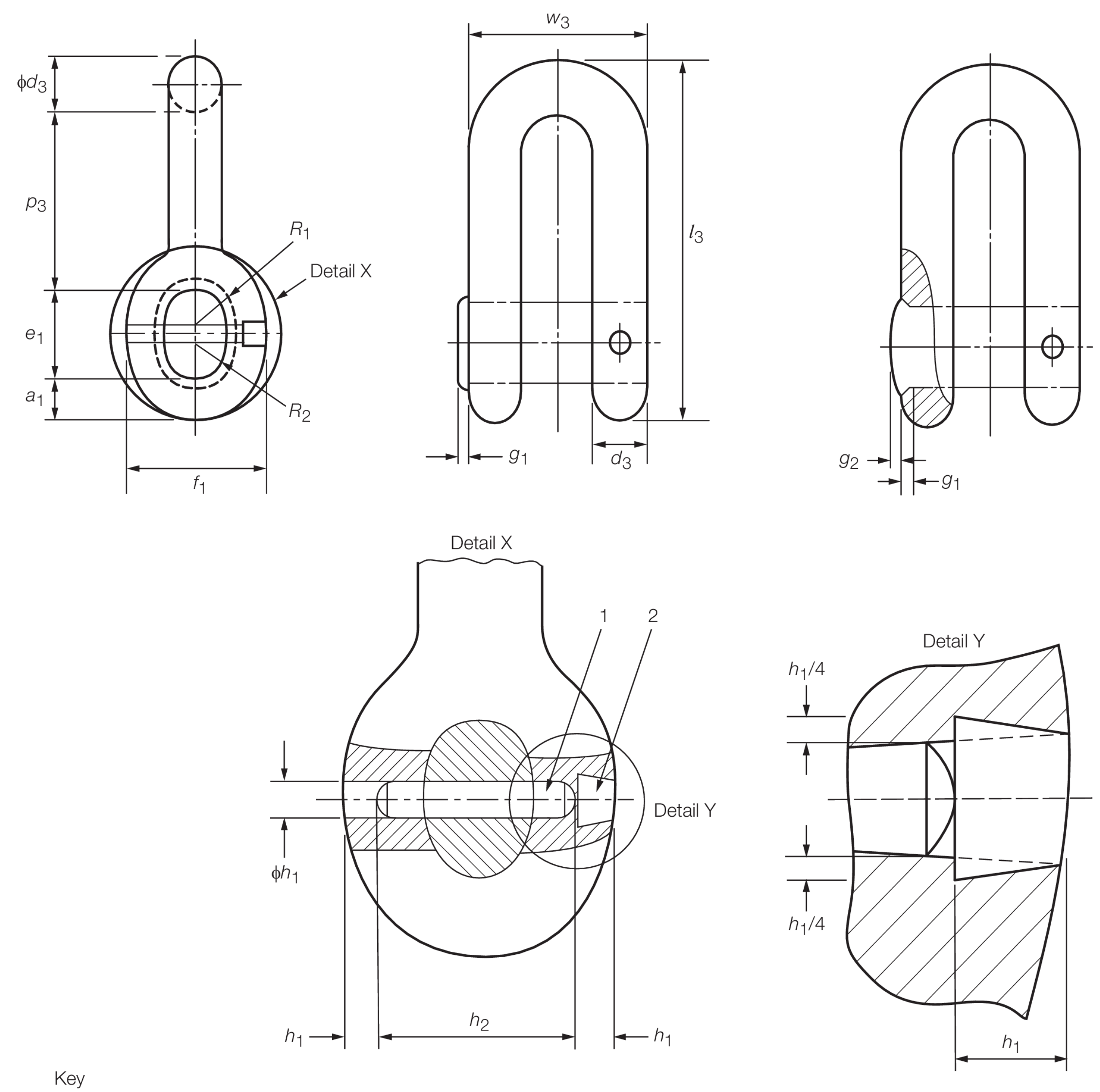
d = nominal diameter of common stud link
d_1 = nominal diameter of enlarged stud link = 1,1d
l_1 = 6d_1 ≈ 6,6d
p_1 = 4d_1 ≈ 4,4d
w_1 = 3,6d_1 ≈ 3,96d

Figure 10.2.3 Enlarged link



d = nominal diameter of common stud link
d_2 = nominal diameter of end link = 1,2d (d_2 = 1,2d)
l_2 = $p_2 + 2d_2 \approx 6{,}75d$
p_2 = $3{,}65d_2 \approx 4{,}35d$
w_2 = $3{,}3d_2 \approx 4d$

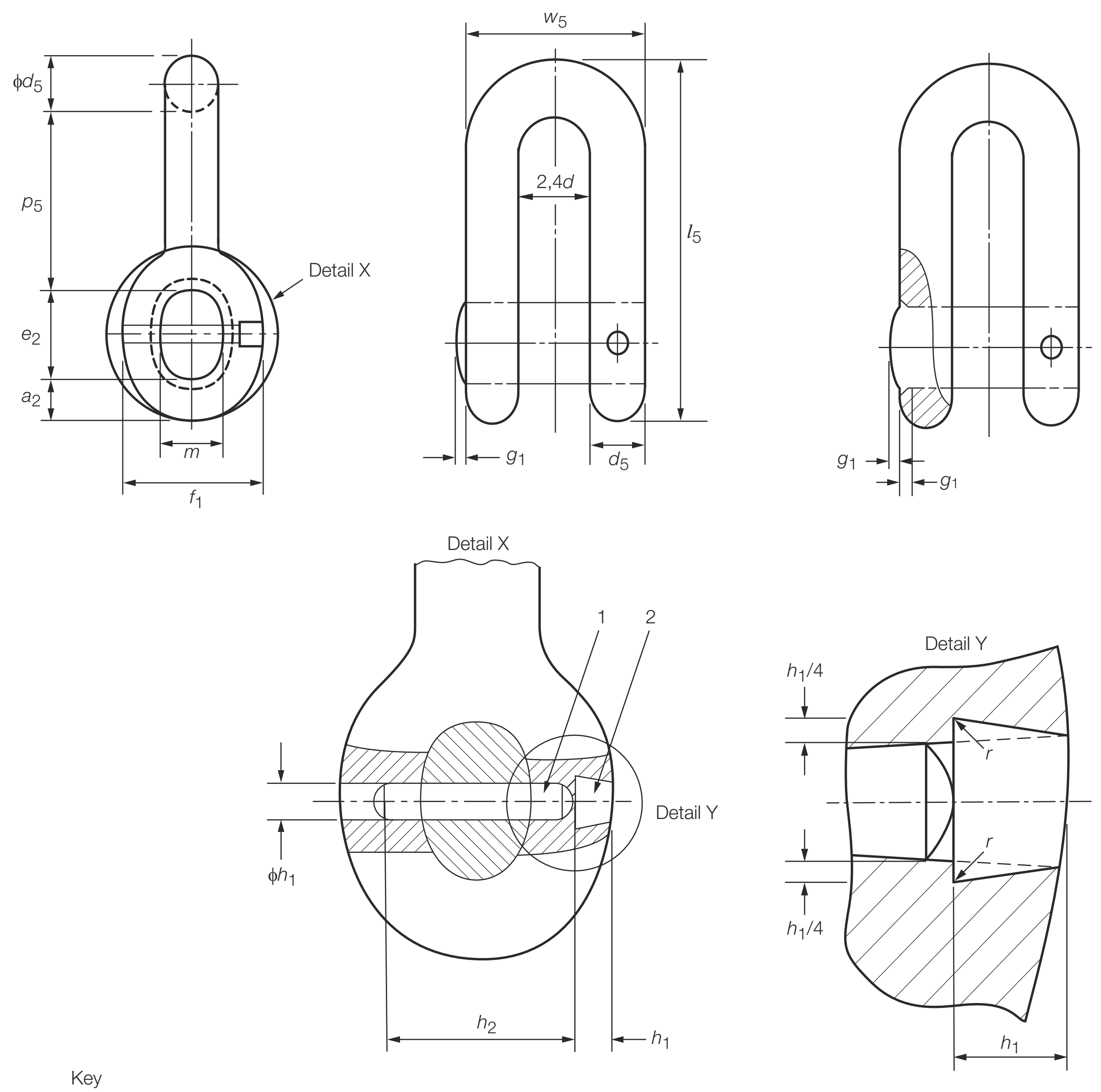
Figure 10.2.4 End link



Key
1 retaining pin
2 dovetail chamber

d	=	nominal diameter of common stud link	f_1	=	2,8d
d_3	=	nominal diameter of joining shackle = 1,3d	g_1	=	0,2d
l_3	=	7,1d	g_2	=	0,1d
p_3	=	$l_3 - (d_3 + a_1 + e_1)$ = 3,4d	h_1	=	nominal diameter of taper pin
w_3	=	4d	h_2	=	nominal length of taper pin
a_1	=	0,8d	R_1	=	0,6d
e_1	=	1,6d	R_2	=	0,5d

Figure 10.2.5 Dee shackle

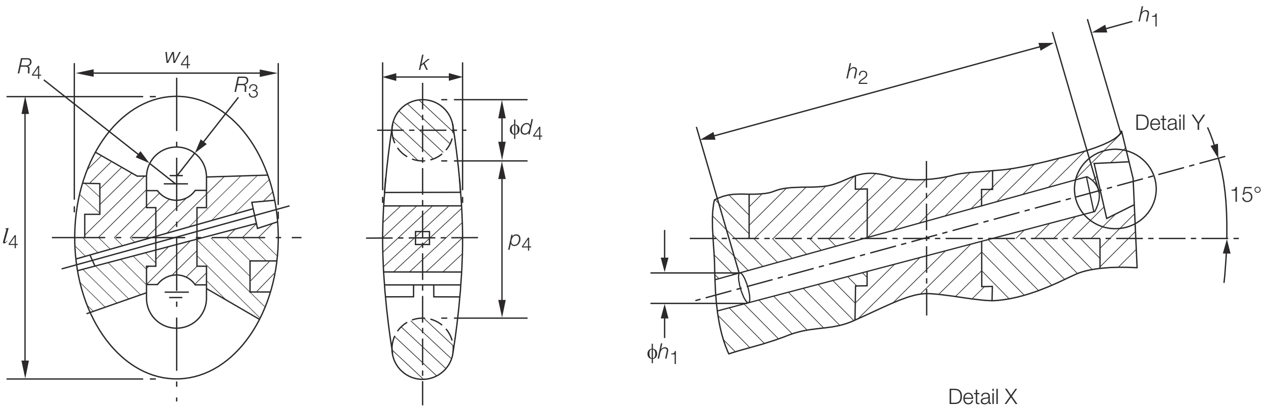


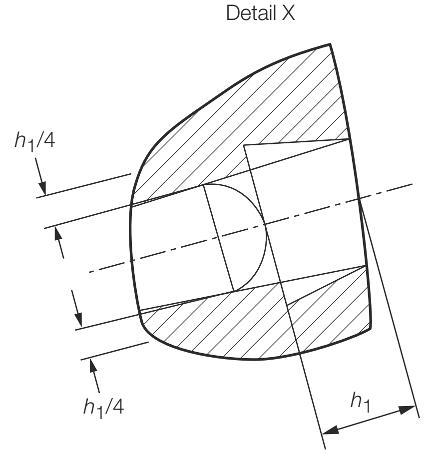
Key
1 retaining pin
2 dovetail chamber

d = nominal diameter of common stud link
d_5 = nominal diameter of end shackle = 1,4d
l_5 = 8,7d
p_5 = $l_5 - (d_5 + a_2 + e_2)$ = 4,5d
w_5 = 5,2d
a_2 = 0,9d
e_2 = 1,8d

f_2 = 3,1d
g_1 = 0,2d
g_2 = 0,1d
m = 1,4d
h_1 = nominal diameter of taper pin
h_2 = nominal length of taper pin

Figure 10.2.6 End shackle

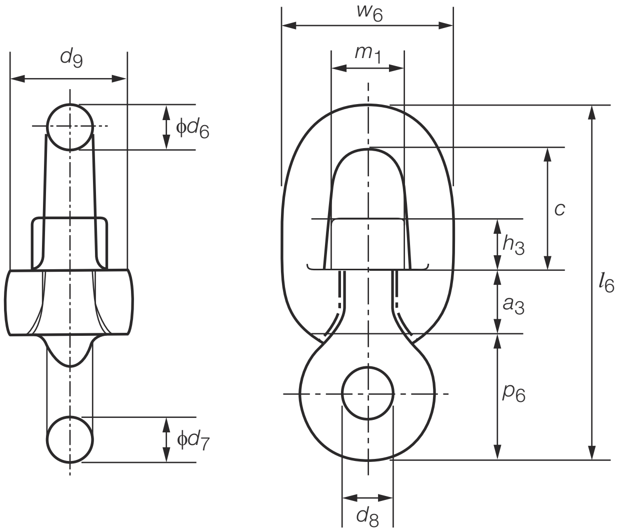




Key

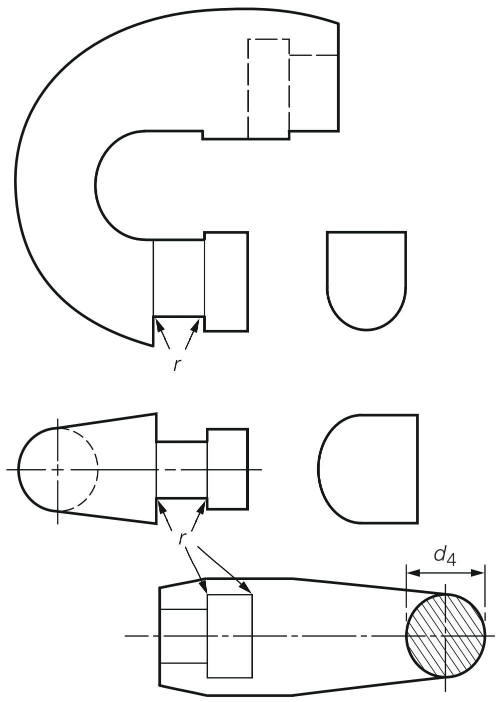
Detail X	=	dovetail chamber for retaining pellet
d	=	nominal diameter of common stud link
d_1	=	nominal diameter of Kenter type joining shackle = d
l_4	=	6d
p_4	=	4d
w_4	=	4,2d
h_1	=	nominal diameter of taper pin
h_2	=	nominal length of taper pin
k	=	1,52d
R_3	=	0,67d
R_4	=	1,83d

Figure 10.2.7 Lugless shackle



d = nominal diameter of common stud link
d_6 = nominal diameter of swivel = 1,2d
l_6 = 9,7d
p_6 = d_9 = 3,4d
w_6 = 4,7d
d_7 = 1,1d
a_3 = 1,75d
m_1 = 2d
h_3 = d_8 = 1,4d
c = 3,35d

Figure 10.2.8 Swivel



The radii indicated by *r* are to be not less than 0,03 x d_4

Figure 10.2.9 Lugless shackle of the Kenter type

■ *Section 3*
Stud link mooring chain cables

3.1 Scope

3.1.1 Provision is made in this Section for five grades, R3, R3S, R4, R4S and R5, of stud link chain intended for offshore mooring applications such as mooring of mobile offshore units, offshore loading systems and gravity based structures during fabrication.

3.1.2 Design of chain cables must be to a recognised Standard, such as ISO 1704; alternatively, the design may be specifically approved by LR.

3.1.3 In addition, chain cable conforming to the requirements of the current edition of API specification 2F is acceptable provided that it has been manufactured, inspected and tested under survey by LR, and that the bar stock has also been certified by LR in accordance with *Ch 3, 9 Bars for welded chain cables*.

3.2 Manufacture

3.2.1 All grades of chain cable and accessories are to be manufactured by approved procedures at works approved by LR. A list of approved manufacturers for stud link chain cables is published separately by LR.

3.2.2 The works in which the chain is manufactured is to have a quality system approved by LR. The provision of such a quality system is required in addition to and not in lieu of the witnessing of tests by a Surveyor.

3.2.3 Approval is confined to a single works and is limited to one grade of cable made from bar from a nominated and approved supplier. Separate approvals are required if steel bar is supplied from more than one works and for other grades of cable, *see also Ch 3, 9 Bars for welded chain cables*.

3.2.4 Details of the method of manufacture and the specification of the steel, are to be submitted.

3.2.5 Offshore mooring chains are to be made in continuous lengths by flash-butt welding.

3.2.6 Bar material may be heated either by electric resistance or in a furnace. For electrical resistance heating, the process is to be controlled by an optical heat sensor. For furnace heating, thermocouples in close proximity to the bars are to be used for control and the temperature is to be continuously recorded. In both cases, the controls are to be checked at least once every eight hours and records taken.

3.2.7 The following welding parameters (as approved in the weld procedure) are to be controlled during welding of each link:

(a) platen motion;
(b) current as a function of time; and
(c) hydraulic pressure.

The controls are to be checked at least once every four hours.

3.2.8 The records of bar heating, flash-butt welding and heat treatment are to be made available to the Surveyor when required.

3.2.9 As far as practicable, consecutive links in all chain cable should originate from a single batch of bar stock (*see Ch 3, 9.6 Mechanical tests 9.6.1*) and indicating marks should be stamped on the final link formed from one batch and the first link formed from a separate batch.

3.3 Dimensions and tolerances

3.3.1 The form and proportions of links and shackles are to be in accordance with ISO/1704, *see Figure 10.2.2 Common link*. Link tolerances are to be in accordance with *Ch 10, 3.3 Dimensions and tolerances 3.3.2*.

3.3.2 Diameter measured at the crown:

Minus 1 mm when $d_c \leq 40$ mm

Minus 2 mm when 40 mm $< d_c \leq 84$ mm

Minus 3 mm when 84 mm $< d_c \leq 122$ mm

Minus 4 mm when 122 mm $< d_c \leq 152$ mm

Minus 6 mm when 152 mm $< d_c \leq 184$ mm

Minus 7,5 mm when 184 mm $< d_c \leq 210$ mm

For diameters of 20mm or greater, the plus tolerance on the diameter at the crown measured perpendicular to the plane of the link, d_p, is not to exceed 5 per cent, and the cross-sectional area at the crown is to have no negative tolerance. For diameters less than 20mm, the plus tolerance is to be agreed between the chain manufacturer and bar material supplier.

3.3.3 The diameter measured at locations other than the crown is to have no negative tolerance. For diameters of 20mm or greater, the plus tolerance may be up to 5 percent of the nominal diameter except at the butt weld where it is to be in accordance with the manufacturer's specification, which is to be agreed by LR. For diameters less than 20mm, the plus tolerance is to be agreed between the chain manufacturer and bar material supplier.

3.3.4 The maximum allowable tolerance on a length of five links measured in accordance with *Ch 10, 2.11 Dimensional inspection 2.11.1* is +2,5 per cent. No under-tolerance is permitted.

3.3.5 A manufacturing tolerance on all other dimensions of ±2,5 per cent is acceptable subject to all parts fitting properly together.

3.3.6 The tolerances for common links are to be measured in accordance with *Table 10.3.1 Stud link chain cable common link tolerances* .

3.3.7 All measurements are to be made on links selected by the Surveyor and are to be carried out to the Surveyor's satisfaction.

3.3.8 Studs are to be located in the links centrally, and at right angles to the sides of the link, although the studs of the final link at each end of any length may also be located off-centre to facilitate the insertion of the joining shackle. The tolerances in accordance with *Table 10.3.1 Stud link chain cable common link tolerances* are acceptable provided that the stud fits snugly and its ends lie flush against the inside of the link.

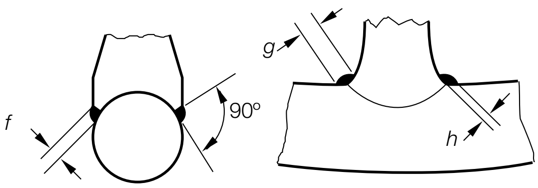
3.4 Studs

3.4.1 The studs are to be made of steel corresponding to that of the chain or in compliance with a specification approved by LR. In general, the carbon content should not exceed 0.23 per cent if the studs are to be welded in place.

3.4.2 Studs may be welded into grade R3 and R3S chains. The welding of studs into grade R4, R4S and R5 chain is not permitted unless specially approved.

3.4.3 In all cases where studs are welded into links, this is to be carried out in accordance with *Ch 10, 2.7 Welding of studs*.

3.4.4 The size of the stud welds is to be in accordance with *Figure 10.3.1 Dimensions and tolerances of stud welds*.



Dimension Designation	Nominal Dimension	Minus Tolerance
f	0,10*d*	0,01*d*
g	0,20*d*	0,02*d*
h	0,09*d*	0,01*d*

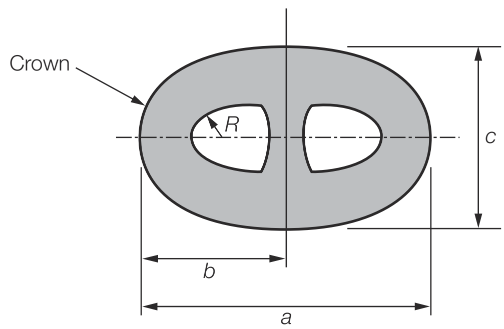
d = Nominal diameter of barstock

3450/02

Figure 10.3.1 Dimensions and tolerances of stud welds

Table 10.3.1 Stud link chain cable common link tolerances

The internal link radii (*R*) and external radii should be uniform



Designation	Description	Nominal dimension of the link	Minus tolerance	Plus tolerance
a	Link length	6*d*	0,15*d*	0,15*d*
b	Link half length	*a**/2	0,10*d*	0,10*d*
c	Link width	3,6*d*	0,09*d*	0,09*d*
e	Stud angular misalignment	0 degrees	4 degrees	4 degrees
R	Inner radius	0,65*d*	0	–

Symbols
d = nominal diameter of chain
*a** = actual link length

3.4.5 All stud welds are to be visually inspected. At least 10 per cent of all stud welds within each length of chain are to be examined by magnetic particle inspection after proof load testing. Stress raising defects such as cracks, lack of fusion, gross porosity, and undercuts exceeding 1 mm are not permitted; if any such defects are found, then all stud welds in that length of chain are to be examined by means of magnetic particle inspection.

3.4.6 Where plastic straining is used to set studs, the applied load is not to be greater than that qualified in approval tests. The combined effect of shape and depth of the impression of the stud in the link is not to cause any harmful notch effect or stress concentration.

3.5 Heat treatment of completed chain cables

3.5.1 The chain is to be normalised, normalised and tempered or quenched and tempered in accordance with the specification approved by LR.

3.5.2 The chains are to be heat treated in a continuous furnace; batch heat treatment is not permitted.

3.5.3 The temperature and time, or temperature and chain speed, are to be controlled and continuously recorded.

3.5.4 Heat treatment is to be carried out prior to the proof loading and breaking tests.

3.5.5 Calibration of furnaces is to be verified by measurement and recording of actual link temperature (surface and internal).

3.6 Testing of completed chain cables

3.6.1 All chain cables are to be tested in the presence of a Surveyor, at a proving establishment recognised by LR. A list of recognised proving establishments is published by LR. In addition to the requirements stated in this Chapter, attention must be given to any relevant statutory requirements of the National Authority of the country in which the ship is to be registered.

3.6.2 The entire length of chain cable is to be subjected to a proof loading test in an approved testing machine and is to withstand the load given in *Table 10.3.2 Test loads for mooring chain cables* for the appropriate grade and size of cable.

Table 10.3.2 Test loads for mooring chain cables

Nominal diameter *d*	Grade R3			Grade R3S			Grade R4			Grade R4S			Grade R5		
	Proof test load		Break test load	Proof test load		Break test load	Proof test load		Break test load	Proof test load		Break test load	Proof test load		Break test load
	Stud link chain	Studless chain		Studless chain	Stud link chain		Stud link chain	Studless chain		Stud link chain	Studless chain		Stud link chain	Studless chain	
mm	kN	kN	kN	kN	kN	kN	kN	kN	kN	kN	kN	kN	kN	kN	kN
50	1480	1480	2230	1800	1740	2490	2160	1920	2740	2400	2130	3040	2510	2230	3200
52	1594	1594	2402	1939	1874	2682	2327	2068	2952	2585	2295	3275	2704	2402	3447
54	1712	1712	2580	2083	2013	2881	2499	2222	3170	2777	2465	3517	2904	2580	3703
56	1834	1834	2764	2231	2156	3086	2677	2380	3396	2974	2640	3768	3111	2764	3966
58	1960	1960	2953	2383	2304	3297	2860	2542	3628	3178	2820	4025	3323	2953	4237
60	2089	2089	3147	2540	2455	3514	3048	2710	3867	3387	3006	4290	3542	3147	4516
62	2221	2221	3347	2701	2611	3737	3242	2881	4112	3602	3196	4562	3767	3347	4802
64	2357	2357	3551	2867	2771	3965	3440	3058	4364	3822	3392	4841	3997	3551	5096
66	2496	2496	3761	3036	2935	4200	3643	3238	4621	4048	3593	5127	4233	3761	5397
68	2639	2639	3976	3209	3102	4440	3851	3423	4885	4279	3798	5420	4475	3976	5706

70	2785	2785	4196	3387	3274	4685	4064	3613	5156	4516	4008	5720	4723	4196	6021
73	3010	3010	4535	3660	3538	5064	4392	3904	5572	4881	4331	6182	5104	4535	6507
76	3242	3242	4884	3942	3811	5454	4731	4205	6001	5257	4665	6658	5498	4884	7009
78	3400	3400	5123	4135	3997	5720	4962	4411	6295	5514	4893	6984	5766	5123	7351
81	3643	3643	5490	4431	4283	6130	5317	4726	6745	5908	5243	7484	6179	5490	7877
84	3893	3893	5866	4735	4577	6550	5682	5051	7208	6313	5603	7997	6602	5866	8418
87	4149	4149	6252	5046	4878	6981	6056	5383	7682	6729	5972	8523	7037	6252	8971
90	4412	4412	6647	5365	5187	7422	6439	5723	8167	7154	6349	9062	7482	6647	9539
92	4590	4590	6916	5582	5396	7722	6699	5954	8497	7443	6606	9428	7784	6916	9924
95	4862	4862	7326	5913	5716	8180	7096	6307	9001	7884	6997	9987	8246	7326	10512
97	5047	5047	7604	6138	5933	8490	7365	6547	9343	8184	7263	10366	8559	7604	10911
100	5328	5328	8028	6480	6264	8964	7776	6912	9864	8640	7668	10944	9036	8028	11520
102	5519	5519	8315	6712	6488	9285	8054	7159	10217	8949	7942	11336	9359	8315	11932
105	5809	5809	8753	7065	6829	9773	8478	7536	10754	9420	8360	11932	9851	8753	12560
107	6005	6005	9048	7304	7060	10103	8764	7790	11118	9738	8643	12335	10184	9048	12984
111	6404	6404	9650	7789	7529	10775	9347	8308	11856	10385	9217	13154	10861	9650	13847
114	6709	6709	10109	8159	7887	11287	9791	8703	12420	10879	9655	13780	11378	10109	14506
117	7018	7018	10574	8535	8251	11807	10242	9104	12993	11380	10100	14415	11902	10574	15174
120	7331	7331	11047	8916	8619	12334	10700	9511	13573	11889	10551	15059	12434	11047	15852
122	7542	7542	11365	9173	8868	12690	11008	9785	13964	12231	10855	15493	12792	11365	16308
124	7755	7755	11686	9432	9118	13048	11319	10061	14358	12576	11161	15930	13153	11686	16768
127	8078	8078	12171	9824	9497	13591	11789	10479	14955	13099	11626	16592	13700	12171	17466
130	8404	8404	12663	10221	9880	14139	12265	10903	15559	13628	12095	17262	14253	12663	18171
132	8623	8623	12993	10488	10138	14508	12585	11187	15965	13984	12411	17713	14625	12993	18645
137	9178	9178	13829	11162	10790	15441	13395	11906	16992	14883	13209	18852	15565	13829	19844
142	9741	9741	14677	11847	11452	16388	14216	12637	18033	15796	14019	20008	16520	14677	21061
147	10311	10311	15536	12540	12122	17347	15048	13376	19089	16720	14839	21179	17487	15536	22294
152	10887	10887	16405	13241	12800	18317	15890	14124	20156	17655	15669	22363	18464	16405	23540
157	11469	11469	17282	13949	13484	19297	16739	14879	21234	18599	16507	23559	19452	17282	24799
162	12056	12056	18166	14663	14174	20284	17596	15641	22320	19551	17351	24764	20447	18166	26068
167	12647	12647	19056	15381	14869	21278	18458	16407	23414	20508	18201	25977	21448	19056	27345
172	13240	13240	19950	16103	15566	22276	19324	17177	24513	21471	19055	27196	22455	19950	28628
177	13836	13836	20847	16827	16267	23278	20193	17949	25615	22437	19912	28420	23465	20847	29915
182	14433	14433	21746	17553	16968	24282	21064	18723	26720	23404	20771	29645	24477	21746	31205
187	15029	15029	22646	18279	17670	25286	21935	19498	27825	24372	21630	30871	25489	22646	32496

192	15626	15626	23544	19004	18371	26289	22805	20271	28929	25339	22488	32096	26500	23544	33785
197	16220	16220	24440	19727	19070	27290	23673	21043	30029	26303	23344	33317	27509	24440	35071
202	16813	16813	25332	20448	19766	28286	24537	21811	31126	27264	24196	34534	28513	25332	36351
207	17401	17401	26220	21164	20459	29277	25397	22575	32216	28219	25044	35744	29512	26220	37625
210	17753	17753	26749	21591	20872	29868	25910	23031	32867	28788	25550	36465	30108	26749	38385
Grade R3															
Proof test load	Stud link chain	$0{,}0148d^2 (44 - 0{,}08d)$													
	Studless chain	0,0148d2 (44 – 0,08*d*)													
Break test load		0,0223d2 (44 – 0,08*d*)													
Grade R3S															
Proof test load	Stud link chain	$0.0180d^2 (44 - 0{,}08d)$													
	Studless chain	$0{,}0174d^2 (44 - 0{,}08d)$													
Break test load		$0{,}0249d^2 (44 - 0{,}08d)$													
Grade R4															
Proof test load	Stud link chain	$0{,}0216d^2 (44 - 0{,}08d)$													
	Studless chain	$0{,}0192d^2 (44 - 0{,}08d)$													
Break test load		$0{,}0274d^2 (44 - 0{,}08d_c)$													
Grade R4S															
Proof test load	Stud link chain	$0{,}0240d^2 (44 - 0{,}08d)$													
	Studless chain	$0{,}0213d^2 (44 - 0{,}08d)$													
Break test load		$0{,}0304d^2 (44 - 0{,}08d)$													
Grade R5															
Proof test load	Stud link chain	$0{,}0251d^2 (44 - 0{,}08d)$													
	Studless chain	$0{,}0223d^2 (44 - 0{,}08d)$													
Break test load		$0{,}0320d^2 (44 - 0{,}08d)$													

3.6.3 Care should be taken to obtain a uniform stress distribution in the links being tested.

3.6.4 The chain is to be shot or sand blasted prior to testing in order to ensure that its surfaces are free from scale, paint or other coating for inspection.

3.6.5 On completion of the proof load test, each link is to be visually examined and is to be free from significant defects such as mill defects, surface cracks, dents and cuts, especially where gripped by clamping dies during flash butt welding. Studs are to be securely fastened and any burrs, irregularities and rough edges are to be removed by careful grinding.

3.6.6 All flash butt welds, including the area gripped by the clamping dies, are to be examined by magnetic particle inspection. The area is to be free from cracks, lack of fusion, gross porosity and any other stress concentrations.

3.6.7 Surface defects in the region of the flash butt welds may be removed by grinding, provided that the depth of grinding does not exceed five per cent of the link diameter and is smoothly contoured into the surrounding material. The final dimensions are still to conform with the agreed standard.

3.6.8 All flash butt welds are also to be examined by ultrasonic inspection and are to be free from defects such as internal cracks or lack of fusion.

3.6.9 All non-destructive examination is to be carried out in accordance with approved procedures, in accordance with *Ch 1, 5 Non-destructive examination*.

3.6.10 All non-destructive examination operators are to be qualified to a minimum Level II, qualified in accordance with a recognised standard.

3.6.11 After proof testing, the entire chain is to be checked for length, five links at a time with an overlap of two links, which is to include the first five links, to ensure that the chain meets the tolerances given in *Ch 10, 2.11 Dimensional inspection 2.11.12*. The measurements are to be made while the chain is loaded to about 10 per cent of the proof load.

3.6.12 The links held in the end blocks may be excluded from these measurements.

3.6.13 If the length over five links is less than the nominal, the chain may be stretched by loading above the specified proof test load provided that the applied load is not greater than ten per cent above the proof test load, and that only random lengths of the chain need to be stretched.

3.6.14 Loads used for plastic straining to set studs are not to exceed those approved in qualification tests.

3.6.15 Checks of all other dimensions are to be made on at least five per cent of the links in the cable.

3.6.16 If any link fails to meet the dimensional tolerance requirements (*see Ch 10, 3.3 Dimensions and tolerances*), measurements are to be made on 20 more links on each side of the incorrect one. If failure to meet any particular dimensional requirements occurs in more than two of the measured links, then all the links are to be dimensionally checked.

3.6.17 Should any link be found to be defective or fail to meet the dimensional tolerance requirements or if a five link length of chain exceeds the specified tolerance, the unsatisfactory links are to be removed from the chain and connecting common links complying with the requirements of *Ch 10, 3.7 Connecting common links or substitute links* inserted in their places.

3.6.18 The chain is then to be subjected to a further proof load test and re-examined.

3.6.19 The number of connecting common links which may be used to replace defective links is not to exceed three in any 100m length of chain. The number and type of joining shackles which may be used are to be subject to the written agreement of the end user.

3.6.20 If a link breaks during proof load testing, a sample consisting of three common links is to be taken from each side of the broken link and subjected to a breaking test as detailed in *Ch 10, 3.6 Testing of completed chain cables 3.6.21* and *Ch 10, 3.6 Testing of completed chain cables 3.6.22*. If either of these samples fails, the proof loaded length of cable is not to be accepted. A thorough examination of all broken links is to be made to determine the cause of failure and, after evaluation, LR will consider the extent of cable which is to be rejected and also the possibility that similar factors to those which caused the failure may also be present in other parts of the cable, or other chain cables. The Surveyor is to be advised in advance of all examinations, with reasonable notice being given.

3.6.21 In addition to the requirements of *Ch 10, 3.6 Testing of completed chain cables 3.6.2*, three link samples are to be selected by the Surveyors from the completed chain for breaking tests. The number of tests required is to be in accordance with *Table 10.3.3 Frequency of break and mechanical tests*. Extra links are to be provided for the mechanical tests detailed in *Ch 10, 3.6 Testing of completed chain cables 3.6.25*. All test links are to be made as part of the chain cable and are to be heat treated with it. These may be removed from the cable prior to heat treatment provided that each sample is heat treated with, and in the same manner as, the chain it represents prior to selection of the mechanical test specimens. They are to be properly identified with the length of chain they represent.

Table 10.3.3 Frequency of break and mechanical tests

Nominal chain diameter mm	Maximum sampling interval m (*See* Note)
Min. — 48	91
49 — 60	110
61 — 73	131
74 — 85	152
86 — 98	175
99 — 111	198
112 — 124	222
125 — 137	250

138 — 149	274
150 — 162	297
163 — 175	322
176 — 186	346
187 — 199	370
199 — 210	395

Note If the sampling interval contains links made from more than one cast, extra break and mechanical tests are required so that tests are made on every cast.

3.6.22 Breaking test specimens are to withstand the load given in *Table 10.3.2 Test loads for mooring chain cables* for the appropriate grade and size of cable for a period of 30 seconds. The specimen is considered to have passed this test if it has shown no sign of fracture after application of the required load.

3.6.23 If a breaking test specimen fails, two further specimens are to be cut from the same sampling length and both are to be subjected to the breaking test load. If one of the re-test specimens fails the length is to be rejected. All the broken links are to be subjected to an investigation into the cause of failure. LR will then decide which lengths of chain can be accepted and on further action.

3.6.24 For large diameter cables where the required breaking load is greater than the capacity of the testing machines, special consideration will be given to acceptance of an alternative testing procedure.

3.6.25 One tensile and three sets of Charpy V-notch impact test specimens are to be taken from links cut from the heat treated and proof loaded chain at intervals no greater than those indicated in *Table 10.3.3 Frequency of break and mechanical tests* provided that every cast is sampled. The tensile specimen and one set of impact specimens are to be taken from the side of the link opposite the weld. One set of impact test specimens is to have the notches positioned at the centre of the flash butt weld and the third set is to be taken from the bend. All the specimens are to be taken from positions in accordance with *Figure 10.3.2 Sampling of chain links*.

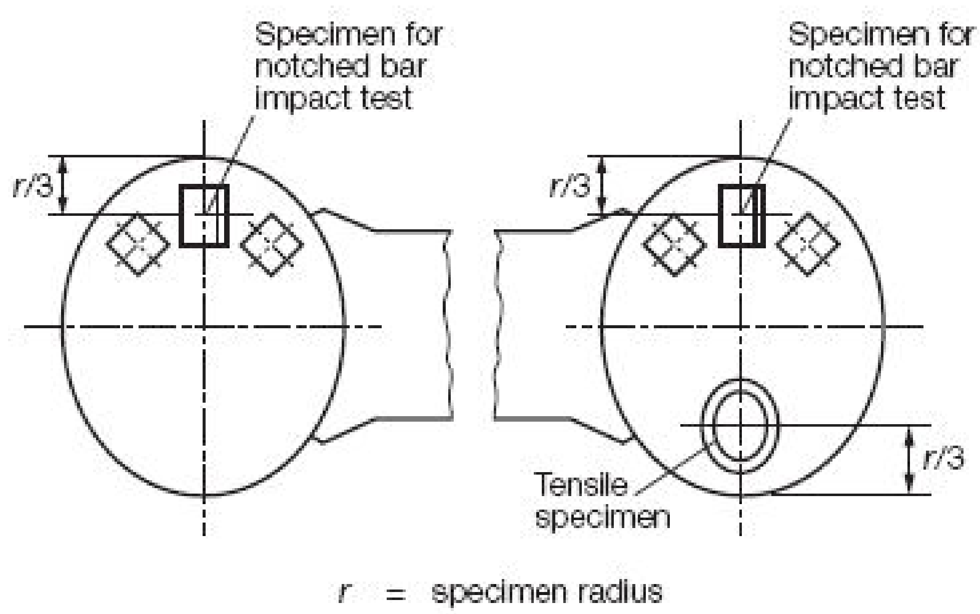


Figure 10.3.2 Sampling of chain links

3.6.26 The frequency of testing at the link bends may be reduced at the discretion of LR provided it can be verified that the required toughness is achieved consistently.

3.6.27 The results of the mechanical tests are to comply with the requirements of *Table 10.3.4 Mechanical properties of chain cable materials*.

Table 10.3.4 Mechanical properties of chain cable materials

Grade	Yield stress N/mm^2 minimum	Tensile strength N/mm^2	Elongation % minimum	Reduction of area % minimum (*See* Note 3)	Charpy V-notch impact tests		
					Test temperature ºC	Average energy J minimum	Average energy flash weld J minimum
R3	410 (*See* Note 1)	690 minimum (*See* Note 1)	17	50	0	60	50
					–20 (*See* Note 2)	40	30
R3S	490 (*See* Note 1)	770 minimum (*See* Note 1)	15	50	0	65	53
					–20 (*See* Note 2)	45	33
R4	580 (*See* Note 1)	860 minimum (*See* Note 1)	12	50	–20	50	36
R4S (*See* Note 4)	700 (*See* Note 1)	960 (*See* Note 1)	12	50	–20	56	40
R5 (*See* Note 4)	760 (*See* Note 1)	1000 (*See* Note 1)	12	50	–20	58	42

Note 1. The ratio of yield strength to tensile strength should not exceed 0,92.

Note 2. Testing may be carried out at either 0°C or –20°C.

Note 3. For cast fittings, the minimum values for reduction of area are to be 40% for Grades R3 and R3S and 35% for Grades R4, R4S and R5.

Note 4. The maximum hardness for Grade R4S is to be HB330, and for Grade R5 is to be HB340.

3.6.28 If the tensile test requirements are not achieved, two further specimens from the same sample are to be tested. The related length of chain will be considered acceptable if both re-test specimens meet the requirements but failure of either of the re-test specimens will result in rejection of the sampling length of chain represented by the tests.

3.6.29 If the impact test requirements are not achieved, re-tests may be carried out in accordance with *Ch 2, 1.4 Re-testing procedures* . Failure to meet the re-test requirements will result in rejection of the sampling length of chain represented by the tests.

3.6.30 The mass per unit length of stud link mooring cable is to comply with *Table 10.3.5 Mass per unit length of chain cable*.

Table 10.3.5 Mass per unit length of chain cable

Nominal chain diameter (mm)	Mass per unit length $0{,}0219d^2$ (kg/m)
50	55
55	66
60	79
65	93
70	107
75	123

80	140
85	158
90	177
95	198
100	219
105	241
110	265
115	290
120	315
125	342
130	370
135	399
140	429
145	460
150	490
155	526
160	561
165	596
170	633
175	671
180	710
185	750
190	791
195	833
200	876
205	920
210	966

3.7 Connecting common links or substitute links

3.7.1 Single links to connect lengths of heat treated chain cable or to substitute for test links or defective links without the necessity for re-heat treatment of the whole length of cable are to be made by the chain manufacturer in accordance with an approved procedure. Separate approvals are required for each grade of chain cable and tests are to be made on the maximum size of chain for which approval is sought.

3.7.2 Manufacture and heat treatment of the connecting common link is not to affect the strength of the adjoining links. The temperature reached by these links is nowhere to exceed 250°C.

3.7.3 The steel bar used is to conform with the specification for the chain and approved by LR in accordance with *Ch 3, 9 Bars for welded chain cables*.

3.7.4 Details of the method of manufacture, including heat treatment, are to be submitted for approval, together with the results of a series of tests laid down by LR.

3.7.5 All links involved in the approval tests are to be destroyed and are not to be used as part of a chain cable.

3.7.6 Every connecting common link included in a chain cable is to be subjected to the proof load appropriate to the grade and size of chain in which it is incorporated as detailed in *Table 10.3.2 Test loads for mooring chain cables*.

3.7.7 Every connecting common link is to be inspected in accordance with *Ch 10, 3.6 Testing of completed chain cables 3.6.5*.

3.7.8 A second identical link is to be made for mechanical tests which are to be in accordance with *Ch 10, 3.6 Testing of completed chain cables 3.6.25*. This test link is also to be inspected in accordance with *Ch 10, 3.7 Connecting common links or substitute links 3.7.7*.

3.7.9 Each connecting common link is to be stamped on the stud with the identification marks listed in *Ch 10, 3.9 Identification 3.9.1* plus a unique number for the link. The adjoining links are also to be stamped on the studs.

3.8 Fittings for offshore mooring chain

3.8.1 Cable fittings are to be manufactured at an approved works. Fittings include, but are not limited to, shackles, triplates, end shackles, swivels, and swivel shackle

3.8.2 The materials from which the fittings are made are to be manufactured at approved works, in accordance with the appropriate requirements of *Ch 4, 1 General requirements* or *Ch 5, 1 General requirements*, and *Ch 10, 3.8 Fittings for offshore mooring chain 3.8.3*. Alternative arrangements may be agreed provided that full details concerning the manufacturer are submitted to LR.

3.8.3 Steel used for fittings must be manufactured by an approved process, and be killed and fine grain treated.

3.8.4 The austenite grain size of steel used for fittings must be 6 or finer as measured in accordance with ASTM E112.

3.8.5 Steel used for forgings or castings for grades R4S and R5 must be vacuum degassed.

3.8.6 For steel used for forgings or castings for grades R4S and R5 the following tests are to be carried out on each heat:

(a) Assessment and quantification of the level of non-metallic micro inclusions. These must be acceptable for the final product.
(b) Macro etching on representative sample, in accordance with ASTM E381 or equivalent, this must be free from any injurious segregation or porosity.
(c) Jominy hardenability tests in accordance with ASTM A255 or equivalent.

The results of these tests are to be supplied by the steel manufacturer, and the results are to be included in the final accessory documentation.

3.8.7 Fittings for chain are to be heat treated in accordance with procedures that have been approved by LR.

3.8.8 All fittings are to be manufactured to a manufacturing specification approved by LR, and provision is to be made for tensile and impact test specimens. The test samples are to be subjected to heat treatment with the fittings they represent. The mechanical test requirements are the same as those for the relevant grade of chain cable, *see Table 10.3.4 Mechanical properties of chain cable materials*.

3.8.9 For fittings for mooring chain, a batch is defined as fittings from the same steel-making heat that have been heat treated together in the same furnace.

3.8.10 Mechanical tests for fittings are to be taken from full size fittings that have been heat treated with the production batch they represent, and the tests are to be taken after the fitting has been proof load tested. It is not permitted to use separate representative coupons unless approved by LR in accordance with *Ch 10, 3.8 Fittings for offshore mooring chain 3.8.14*.

3.8.11 Forged shackle bodies and forged Kenter shackles are to have a set of three Charpy impact tests and a tensile test taken from the crown of the shackle. For smaller diameter shackles, where the geometry does not allow for the tensile test to be taken from the crown, this may be taken from the straight portion from the locations specified in *Figure 10.3.3 Sampling of steel bars, forgings and castings*, with the Charpy impact test specimens on the outside radius.

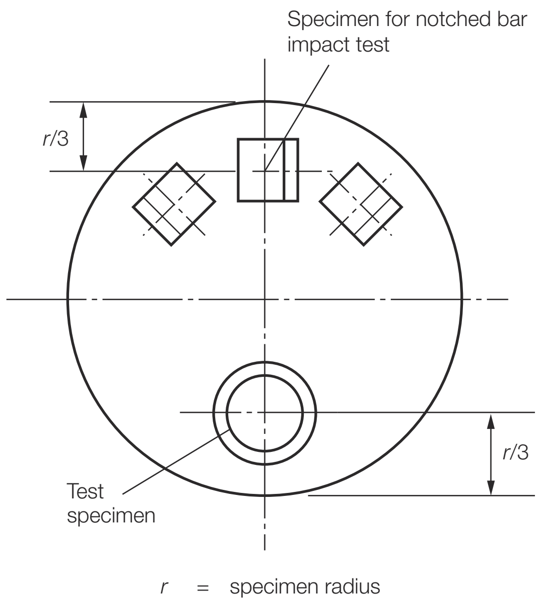


Figure 10.3.3 Sampling of steel bars, forgings and castings

3.8.12 The test pieces for cast shackle bodies and cast Kenter shackles can be taken from the straight portion of the fitting from the locations shown in *Figure 10.3.3 Sampling of steel bars, forgings and castings*.

3.8.13 For fittings with complex geometries the locations of test pieces taken are to be approved by LR.

3.8.14 Where fittings are produced in small batches (less than 5) alternative testing may be approved; a proposal must be submitted in a written procedure for consideration.

3.8.15 Mechanical tests of pins are to be taken as shown in *Figure 10.3.4 Buffer and test piece location for pins* from the mid length of a sacrificial pin of the same diameter as the final pin. For oval pins, the diameter taken is to represent the smaller dimension. Mechanical tests may be taken from an extended pin of the same diameter as the final pin that incorporates a test prolongation and a heat treatment buffer prolongation, where equivalence with mid length test values have been established. The length of the buffer is to be at least equal to 1 pin diameter which is removed after the heat treatment cycle is finished. The test coupon can then be removed from the pin. The buffer and test are to come from the same end of the pin, as shown in *Figure 10.3.4 Buffer and test piece location for pins*.

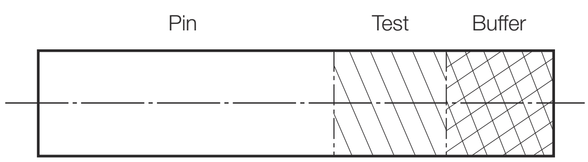


Figure 10.3.4 Buffer and test piece location for pins

3.8.16 Manufacturers intending to supply accessories in the machined condition (e.g. Kenter type shackles) are to submit detailed drawings for approval by LR.

3.8.17 All chain cable accessories, including spares, are to be subjected to the proof loads appropriate to the grade and size of cable for which they are intended, *see Table 10.3.2 Test loads for mooring chain cables*. Prior to this test, the accessories are to be shot or sand blasted to ensure that their surfaces are free from scale, paint or any other coating which could interfere with any subsequent inspection.

3.8.18 The appropriate breaking load as required by *Table 10.3.2 Test loads for mooring chain cables* is to be applied to at least one item out of every batch of up to 25, and this item is to be destroyed and not used as part of an outfit.

3.8.19 If the sample fails to withstand the breaking load without fracture, or in the event of failure of any other test, then the entire batch is to be rejected unless the cause of failure has been determined and it can be demonstrated that the condition causing failure is not present in any of the other accessories in the batch. If this can be demonstrated then two more samples from the same batch may be tested. If either of these samples fails, the batch is to be rejected.

3.8.20 For very large fittings where the required breaking load is greater than the capacity of the testing machine and for individually produced accessories or accessories produced in small batches, proposals for an alternative method of testing will be given special consideration. All proposals for alternative testing methods are to be detailed in writing and submitted.

3.8.21 At least one accessory from each batch is to be checked dimensionally after proof load testing. The manufacturer is to provide a statement that the dimensions comply with the specified requirements.

3.8.22 The following tolerances apply of the unmachined dimensions of all fittings;

(a) nominal diameter plus 5 per cent, minus 0 per cent; and
(b) other dimensions plus or minus 2,5 per cent.

3.8.23 All accessories are to be subjected to close visual examination after proof load testing, particular attention being paid to machined surfaces and highly stressed regions. All accessories are also to be examined by magnetic particle or dye penetrant inspection and ultrasonic testing. All NDE is to be carried out in accordance with *Ch 10, 3.6 Testing of completed chain cables 3.6.9* and *Ch 10, 3.6 Testing of completed chain cables 3.6.10*. The manufacturer is to provide a statement that the non-destructive examination has been carried out with satisfactory results; this statement is to include reference to the techniques used and the operator's qualifications.

3.8.24 All testing is to be carried out to the satisfaction and in the presence of the Surveyor.

3.8.25 Fittings of increased dimensions or higher grade material may be used subject to approval by LR.

3.8.26 Where fittings with increased dimensions, or fittings of a higher material grade are included in an outfit:

(a) each item must be successfully tested at the required breaking load for the chain cable for which it is intended; and
(b) items of increased dimensions are so designed that their breaking strength is not less than 1,4 times the Rule minimum breaking load for the chain cable for which it is intended, and this has been verified by procedure tests.

3.9 Identification

3.9.1 Each length of chain is to be permanently marked with the following:

(a) LR and abbreviated name of LR's local office issuing the certificate.
(b) Certificate number (this may be abbreviated provided it is stated in the certificate).
(c) Grade and proof load of chain.

3.9.2 The chain is to be marked as follows:

(a) at each end (the marking should identify the leading and tail end of each chain),
(b) at intervals not exceeding 100 m,
(c) on all connecting common links or shackles and the immediately adjacent links,
(d) on the first and last common link of each individual heat used in the continuous length.

3.9.3 All identification marks are to be made on the studs and are to be permanent and legible throughout the expected service life of the chain.

3.10 Documentation

3.10.1 A complete Chain Inspection and Testing Report, in booklet form, is to be provided by the chain manufacturer for each continuous chain length, and for each order for chain and fittings. It is to include all dimensional checks, test and inspection reports, non-destructive test reports, process records, as well as any non-conformity, together with corrective action and repair work.

3.10.2 All documents, including reports and appendices, are to contain a reference to the relevant certificate number.

3.10.3 The chain manufacturer is responsible for storing all the documentation in a safe and retrievable manner for a period of at least 10 years.

3.11 Certification

3.11.1 An LR certificate is to be issued for each continuous single length of chain, and each type of fitting, *see Ch 1, 3.1 General*.

3.11.2 Each test certificate is to include the following particulars:

(a) Purchaser's name and order number.
(b) Description and dimensions.
(c) Grade of chain cable.
(d) Identification mark which will enable the full history of the chain to be traced.
(e) Chemical composition.
(f) Details of heat treatment.
(g) Mechanical test results.
(h) Breaking test load.
(i) Proof load.
(j) The number and locations of all connecting common links and all marked links.

■ *Section 4*
Studless mooring chain cables

4.1 Scope

4.1.1 Provision is made in this Section for five grades, R3, R3S, R4, R4S and R5 of studless flash butt welded chain cable intended for long term mooring applications.

4.1.2 The chain is generally expected to be deployed only once for a pre-determined service life.

4.1.3 Each studless chain link design will require to be approved by LR. The plan submitted for this approval is to include the minimum proof and breaking test loads, and the chain mass calculations.

4.2 Manufacture

4.2.1 All the requirements of *Ch 10, 3.2 Manufacture*, with the exception of that relating to studs, apply to the manufacture of studless mooring chain cables.

4.3 Shape and dimensions of links

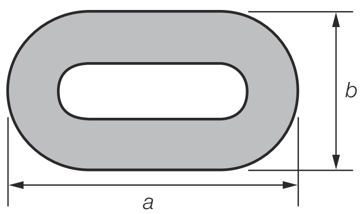
4.3.1 The shape and dimensions of the links are to be in accordance with the approved design.

4.4 Dimensional tolerances

4.4.1 The dimensional tolerances of studless links are to be in accordance with the requirements of *Ch 10, 3.3 Dimensions and tolerances 3.3.1*.

4.4.2 The tolerances for common links are to be measured in accordance with *Table 10.4.1 Studless chain cable common link tolerances*.

Table 10.4.1 Studless chain cable common link tolerances

The internal link radii (*R*) and external radii should be uniform


Designation	Description	Nominal dimension of the link	Minus tolerance	Plus tolerance
a	Link length	6*d*	0,15*d*	0,15*d*
b	Link width	3,35*d*	0,09*d*	0,09*d*
R	Inner radius	0,60*d*	0	—
Symbols				
d = nominal diameter of chain				
Note Other dimensional ratios are subject to special approval.				

4.5 Heat treatment

4.5.1 Heat treatment of the chain is to be in accordance with the requirements of *Ch 10, 3.5 Heat treatment of completed chain cables*.

4.6 Testing of completed chain

4.6.1 All chain cables are to be tested in the presence of a Surveyor, at a proving establishment recognised by LR. A list of recognised proving establishments is published by LR. In addition to the requirements stated in this Chapter, attention must be given to any relevant statutory requirements of the National Authority of the country in which the ship is to be registered.

4.6.2 The entire length of chain cable is to be subjected to a proof load test in an approved testing machine and is to withstand the load given in *Table 10.3.2 Test loads for mooring chain cables* for the appropriate grade and diameter of the chain, *see also Ch 10, 4.1 Scope 4.1.3*.

4.6.3 Inspection after proof load testing is to be in accordance with the requirements given in *Ch 10, 3.6 Testing of completed chain cables 3.6.3*, excluding that related to checking of studs in *Ch 10, 3.6 Testing of completed chain cables 3.6.5*.

4.6.4 In addition to the inspection of the flash butt welded areas as required in *Ch 10, 3.6 Testing of completed chain cables 3.6.6*, the surfaces of the bends of at least 10 per cent of the links are to be examined by magnetic particle inspection and are to be free from cracks or other defects.

4.6.5 If stretching of links is required in order to maintain dimensional tolerances, the load applied is not to exceed the proof load by more than 10 per cent, and only random lengths of the chain need to be stretched.

4.6.6 Breaking load tests are to be carried out in accordance with *Ch 10, 3.6 Testing of completed chain cables 3.6.21* and *Table 10.3.2 Test loads for mooring chain cables* and *Table 10.3.3 Frequency of break and mechanical tests*.

4.6.7 Alternative procedures to breaking load testing (*see Ch 10, 3.6 Testing of completed chain cables 3.6.24*) are not permissible unless prior agreement is given by LR after special consideration.

4.6.8 Mechanical testing is to be carried out in accordance with *Ch 10, 3.6 Testing of completed chain cables 3.6.25* and *Table 3.3.4 Carbon equivalent requirements for higher tensile strength steels up to 100 mm in thickness when supplied in the TM condition*.

4.6.9 The weight of the chain cable is to be in accordance with the approved plan.

4.7 Connecting or substitute links

4.7.1 Connecting links and substitute links are to be in accordance with the requirements of *Ch 10, 3.7 Connecting common links or substitute links*.

4.8 Fittings

4.8.1 Fittings for studless chain are to comply with the requirements of *Ch 10, 3.8 Fittings for offshore mooring chain*.

4.9 Identification

4.9.1 All chain and each fitting is to be identified in accordance with *Ch 10, 3.9 Identification 3.9.1* and *Ch 10, 3.9 Identification 3.9.2*.

4.9.2 Identification marks are to be made on the outside of the straight part of the link, opposite the flash butt weld.

4.10 Certification

4.10.1 Certificates are to be issued in accordance with *Ch 10, 3.11 Certification*.

4.11 Documentation

4.11.1 Documentation in accordance with *Ch 10, 3.10 Documentation* is to be provided by the manufacturer.

■ *Section 5*
Short link chain cables

5.1 Scope

5.1.1 This Section gives the requirements for electrically welded steel short link chain cable for marine use but excluding those applications covered by the *Code for Lifting Appliances in a Marine Environment*.

5.1.2 Provision is made for grade M(4), as defined in ISO 1834.

5.2 Manufacture

5.2.1 Short link chain cables are to be manufactured at works approved by LR. A list of approved manufacturers for short link chain cable is published separately by LR.

5.2.2 The chain is to be supplied in either the normalised or quenched and tempered condition. Heat treatment is to be carried out prior to proof and breaking load testing.

5.2.3 The chain may be galvanised using a hot dipping process provided that this is carried out prior to proof and breaking load testing. If galvanised, it is recommended that the thickness of the zinc coating be not less than 70 microns.

5.2.4 Unless otherwise agreed, the finished chain is to be free from coatings other than zinc.

5.3 Bar material

5.3.1 Bars for the manufacture of short link chain cable are to be made and tested in accordance with the appropriate requirements of *Ch 3, 1 General requirements* and to the requirements of an International or acceptable National Standard.

5.3.2 The bars are to be made at a works approved by LR.

5.3.3 The steel is to be fully killed and fine grain treated.

5.3.4 The steel is to have mechanical properties which will allow the chain to meet the mechanical test requirements of *Ch 10, 5.4 Testing and inspection of chain cables 5.4.7* and *Table 10.5.1 Mechanical test requirements for short link chain cables*.

5.4 Testing and inspection of chain cables

5.4.1 All chain cable of 12,5 mm diameter and above, and all steering chains irrespective of diameter, are to be tested in the presence of a Surveyor at a proving establishment recognised by LR. A list of recognised proving establishments is published by LR. In addition to the requirements stated in this Chapter, attention is to be given to any relevant statutory requirements of the National Authority of the country in which the ship or other marine structure is to be registered.

Table 10.5.1 Mechanical test requirements for short link chain cables

Chain diameter mm	Grade M(4)	
	Proof load kN	Breaking load minimum kN
5	7,9	15,8
6,3	12,5	25
7,1	15,9	31,8
8	20,2	40,4

9	25,5	51
10	29,5	63
11,2	31,5	79
12,5	49,1	98,2
14	63	126
16	81	162
18	102	204
20	126	252
22,4	158	316
25	197	394
28	247	494
32	322	644
36	408	816
40	503	1006
45	637	1274

5.4.2 For chain of diameter less than 12,5 mm, other than steering chains, the manufacturer's tests will be acceptable.

5.4.3 After completion of all manufacturing processes, including heat treatment and galvanising, the whole of the chain is to be subjected to the appropriate proof load specified in *Table 10.5.1 Mechanical test requirements for short link chain cables*.

5.4.4 The whole of the chain is to be inspected after the proof load test and is to be free from significant defects.

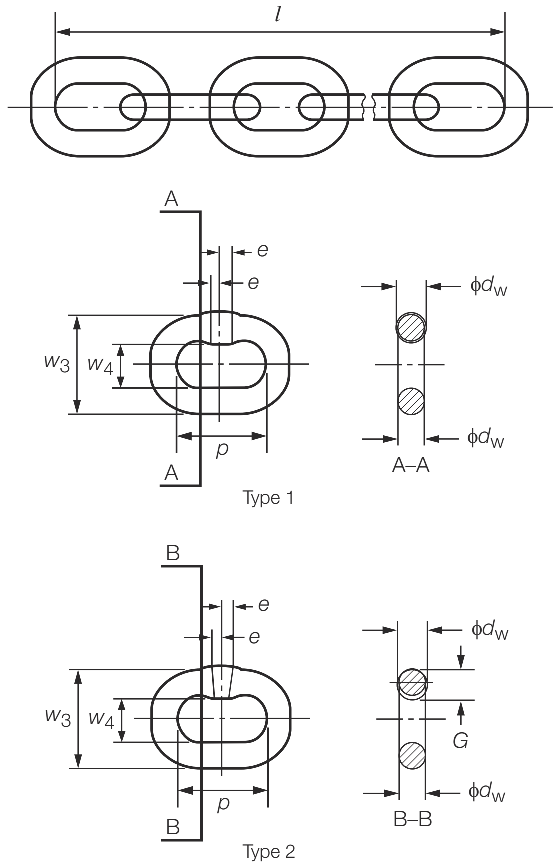
5.4.5 At least one sample, consisting of seven or more links, is to be selected by the Surveyor from each 200 m or less of chain for breaking load tests. Two additional links may be required for engagement in the jaws of the testing machine. These extra links are not to be taken into account in determining the total elongation, *see Ch 10, 5.4 Testing and inspection of chain cables 5.4.7*.

5.4.6 The breaking load is to comply with the appropriate requirements of *Table 10.5.1 Mechanical test requirements for short link chain cables*.

5.4.7 The total elongation of the breaking load sample at fracture, expressed as a percentage of the original inside length of the sample after proof loading, is to be not less than 20 per cent.

5.5 Dimensions and tolerances

5.5.1 The form and proportions of links are to be in accordance with *Figure 10.5.1 Form and proportions of links*.



l = multiple pitch length
p = pitch (internal link length)
d_n = measured diameter of the material, except at the weld
d_w = measured diameter of the material at the weld (Type 1) or weld dimension perpendicular to the plane of the link (Type 2)
G = dimension in other planes as per individual chain specification (Type 2)
e = length affected by welding, on either side of the centre link
w_1 = internal link width away from the weld
w_2 = external link width away from the weld
w_3 = external link width over the weld
w_4 = internal link width at the weld

Figure 10.5.1 Form and proportions of links

5.5.2 Manufacturing tolerances are to be within the following limits:

Nominal diameter, d_n	± 5%
Pitch of chain, p_1	± 3%
Length measured over 11 links l	± 2%
Inside width, w_1	1,35 d_n minimum
Outside width, w	3,6 d_n maximum

The tolerances are to apply after galvanising. All measurements are to be taken after proof testing.

5.6 Identification

5.6.1 All lengths of cable are to be stamped with the following identification marks:

(a) Inspector's mark and date.
(b) Reference mark or number of certificate.
(c) Manufacturer's mark or name.
(d) Chain cable quality mark, M, is to be stamped on at least each twentieth link or at intervals of one metre, whichever is the lesser distance.

5.6.2 Where the inspection is performed under LR`s supervision, the inspector's mark and date are to be replaced by LR and the abbreviated name of LR's local office issuing the certificate.

5.7 Certification

5.7.1 The manufacturer is to supply the Surveyor with a certificate stating compliance with an appropriate ISO standard, and also, in the event of the requirements of *Ch 10, 5.4 Testing and inspection of chain cables* being undertaken other than in the presence of the Surveyor, stating that the test and inspection requirements have been complied with at a recognised proving establishment.

5.7.2 Each test certificate is to include the following particulars:

(a) the quality and description of chain,
(b) identification mark,
(c) nominal size of chain,
(d) proof load,
(e) breaking load,
(f) total elongation at fracture,
(g) where appropriate, the name of the proving establishment.

■ *Section 6*
Steel wire ropes

6.1 Scope

6.1.1 Provision is made in this Section for the requirements for the manufacture, testing and certification of steel wire ropes intended to be used for general marine purposes, as well as permanent anchoring, mooring and marine lifting applications.

6.2 General requirements

6.2.1 For general marine purposes, such as stream wires, towlines and ship mooring lines, the construction is to be in accordance with *Table 10.6.1 Recommended rope construction*. The construction, diameter and strength of steel wire ropes for permanent offshore applications, such as mooring, anchoring and lifting, are covered by other LR Rules. Alternative applications of wire ropes may be accepted, subject to special consideration.

6.2.2 The manufacturer's plant and method of production are to be approved by LR. A list of approved manufacturers of steel wire ropes is published annually in the *List of Approved Manufacturers of Materials*.

Table 10.6.1 Recommended rope construction

Purpose	Construction of rope			Construction of strands
	Strands	Wires	Core	
Stream wires, towlines and mooring lines	6	24	Fibre	15 over 9 over fibre core
	6	37	Fibre	18 over 12 over 6 over 1
	6	26	Fibre	10 over (5 + 5) over 5 over 1
	6	31	Fibre	12 over (6 + 6) over 6 over 1
	6	36	Fibre	14 over (7 + 7) over 7 over 1
	6	41	Fibre	16 over (8 + 8) over 8 over 1
	6	30	Fibre	18 over 12 over fibre core
Towlines and mooring lines used in association with mooring winches	6	31	7 x 7 wire rope	12 over (6 + 6) over 6 over 1
	6	36	7 x 7 wire rope	14 over (7 + 7) over 7 over 1
	6	41	7 x 7 wire rope	16 over (8 + 8) over 8 over 1

6.2.3 For shaped wire, for example, for large diameter ropes for permanent mooring, where there are no established Standards, the manufacturer is to provide evidence by way of test reports that specifications have been developed and agreed with the purchaser and LR for the purposes intended.

6.3 Steel wire for ropes

6.3.1 Steel wire is to be of homogeneous quality, uniform strength and free of defects likely to impair the manufacture and performance of the rope.

6.3.2 For all ropes, the specified minimum tensile strength of the wire is to be 1420, 1570, 1770 or 1960 N/mm^2. The specified minimum tensile strength of the wire is the designated grade for the rope, unless otherwise defined by the purchaser's specification. The actual tensile strength of the wire is not to exceed 120 per cent of the specified minimum tensile strength.

6.3.3 For new rope construction, the manufacturer is to carry out prototype testing suitable for the application of the rope and this is to include tests on wire used for the construction.

6.3.4 Tensile and torsion tests, coating, and adhesion (wrap) tests are to be carried out on wire used for the manufacture of rope.

6.3.5 At least 10 per cent of the spools used for the manufacture of the strand are to be tested. The manufacturer is to demonstrate that tests have been carried out on at least one wire intended for each of the outer and inner strands, and for each diameter and grade used.

6.3.6 The heat number, wire diameter and strength of wire used for a particular construction are to be recorded by the manufacturer.

6.3.7 Torsion tests are to be carried out on the wire by causing one or both of the securing vices to be revolved until fracture occurs (a tensile load not exceeding two per cent of the breaking load of the wire may be applied to keep the wire stretched).

6.3.8 The uncoated wire is to withstand, without fracture, the number of complete twists given for Grades 1 or 3 in *Table 10.6.2 Torsion test*.

6.3.9 The galvanised wire is to withstand, without fracture, the number of complete twists given in the specification, as agreed with the purchaser and LR. In the absence of a suitable specification, the results are to comply with *Table 10.6.2 Torsion test*.

6.3.10 Hot dipped galvanised steel wire is to be used for the manufacture of ropes for marine applications. Depending upon the application, the coating may comply with any of the grades in *Table 10.6.3 Zinc coating*. Grades 1 and 2 are heavy coatings. Grade 3 is the minimum coating weight where the galvanising is carried out prior to final wire drawing. Uncoated wire may be considered for approved applications.

Table 10.6.2 Torsion test

Diameter coated wire mm	Minimum number of twists					
	Grade 2		Grade 1 or 3			
	Minimum strength N/mm^2		Minimum strength N/mm^2			
	1570	1770	1420	1570	1770	1960
<1,3	19	18	29	26	23	23
≥1,3 <2,3	18	17	26	24	21	21
≥2,3 <3,0	16	14	24	22	—	19
≥3,0 <4,0	12	10	20	18	—	17
≥4,0 <4,6	—	—	18	16	—	—
≥4,6 <5,0	—	—	16	14	—	—
≥5,0 <6,0	—	—	14	11	—	—
Note The minimum test length is 100*d* or 300 mm, where *d* is the wire diameter.						

Table 10.6.3 Zinc coating

Diameter of coated wire mm	Zinc coating, minimum g/m^2		
	Grade 1	Grade 2	Grade 3
≥0,20<0,25	—	30	20
≥0,25<0,33	—	45	30
≥0,33<0,40	—	60	30
≥0,40<0,50	60	75	40
≥0,50<0,60	70	90	50
≥0,60<0,80	85	110	60
≥0,80<1,00	95	130	70
≥1,00<1,20	110	150	80
≥1,20<1,50	120	165	90
≥1,50<1,90	130	180	100
≥1,90<2,50	—	205	110
≥2,50<3,20	—	230	125
≥3,20<4,00	—	250	135

6.3.11 The mass per unit area of the zinc coating is to be determined in accordance with a recognised National or International Standard.

6.3.12 Zinc coating tests are to be carried out for each designated grade of wire. The manufacturer is to demonstrate that the coatings are continuous and uniform and suitable for the intended purpose.

6.3.13 Unless otherwise specified by the purchaser, zinc coating tests are to be carried out on the wire prior to stranding.

6.3.14 The adhesion of the coating is to be tested by wrapping the wire round a cylindrical mandrel for 10 complete turns. The ratio between the diameter of the mandrel and that of the wire is to be as in *Table 10.6.4 Wrap test for adhesion of coating*. After wrapping on the appropriate mandrel, the zinc coating is to have neither flaked nor cracked to such an extent that any zinc can be removed by rubbing with a cloth.

Table 10.6.4 Wrap test for adhesion of coating

Coating	Diameter of coated wire mm	Maximum ratio of mandrel to wire diameter
Grade 1 and 2	<1,5	4
	≥1,5	6
Grade 3	<1,5	2
	≥1,5	3

6.4 Tests on completed ropes

6.4.1 Every length of wire rope is to be subjected to a breaking strength test.

6.4.2 A sample of sufficient length is to be provided for the breaking load test. The rope ends are to be enclosed in a suitable socket. Testing is to be carried out in accordance with a recognised National or International Standard.

6.4.3 The rope may be subject to cyclic loading for bedding purposes prior to testing. The rope is to be tested at a suitable strain rate in accordance with a recognised National or International Standard.

6.4.4 The load is to be applied until one wire break is witnessed or 130 per cent of the minimum breaking load is recorded. The maximum recorded load is to be reported by the manufacturer.

6.4.5 Tests in which a breakage occurs adjacent to and as a result of damage from the grips are to be rejected, if the applied load is less than the specified minimum requirement. The rope is to be retested to withstand the agreed minimum breaking load.

6.4.6 With the exception of offshore mooring ropes, consideration may be given to determining the breaking load by summation or aggregating actual test results on individual wires, if facilities are not available for undertaking a breaking test on a production basis. A suitable spin factor or lay-up deduction allowance in accordance with a recognised National or International Standard for the applicable rope diameter, designated grade and construction is to be applied.

6.4.7 Where spin factors or lay-up deduction allowances are proposed by the manufacturer, a report on suitable cyclic load testing of prototype ropes of the same construction, strength and diameter is to be approved by LR. In addition, the manufacturer is to show that a satisfactory breaking load test has been carried out in the previous two years, and witnessed by LR for the same rope construction, diameter and designated grade.

6.4.8 LR may give special consideration to spin factors or lay deductions based on data extrapolated from smaller diameter ropes of the same construction, provided that these ropes have been tested in accordance with *Ch 10, 6.4 Tests on completed ropes 6.4.7*.

6.4.9 All data arising from smaller diameter ropes for the extrapolation in *Ch 10, 6.4 Tests on completed ropes 6.4.8* are to have been derived from tests carried out within two years of the manufacture of the larger diameter rope.

6.4.10 The finished rope is to have no more than one wire connecting weld in any length of 18*d*, where *d* is the diameter of the rope.

6.5 Dimensional inspection

6.5.1 The dimensions and discard criteria are to comply with a recognised National or International Standard.

6.6 Identification

6.6.1 All completed ropes are to be identified with attached labels detailing the rope type, diameter and length.

6.7 Certification

6.7.1 Unless otherwise requested by the purchaser, a manufacturer's certificate, in accordance with *Ch 1, 3.1 General 3.1.3*, is to be issued.

6.7.2 Each test certificate is to contain the following particulars:

- Purchaser's name and order number.
- Details of the rope construction.
- Core material.
- Grade of zinc coating.
- Mechanical test results.
- Adhesion test results.
- Dimensions.
- Method of breaking load testing.
- Breaking load.

■ *Section 7* Fibre ropes

7.1 Manufacture

7.1.1 Fibre ropes intended as mooring lines may be made of coir, hemp, manila or sisal, or may be composed of synthetic (man-made) fibres. They may be three-strand (hawser laid), four-strand (shroud laid) or nine-strand (cable laid), but other constructions will be specially considered.

7.1.2 Each length of rope is to be manufactured from suitable material of good and consistent quality. Rope materials should, in general, comply with a recognised National Standard.

7.1.3 Synthetic fibre ropes are to be suitable for the purpose intended and should comply with a recognised standard.

7.1.4 Weighting and loading matter is not to be added, and any lubricant is to be kept to a minimum. Any rot-proofing or water repellancy treatment is not to be deleterious to the fibre nor is it to add to the weight or reduce the strength of the rope.

7.2 Tests of completed ropes

7.2.1 The breaking load is to be determined by testing to destruction a sample cut from the completed rope.

7.2.2 The minimum test length and the initial test load are to be as given in *Table 10.7.1 Breaking load test*. After application of the initial load, the diameter and evenness of lay up of the sample are to be checked. The sample is then to be uniformly strained at the rate given in *Table 10.7.1 Breaking load test* until it breaks.

Table 10.7.1 Breaking load test

Material	Test length mm minimum	Initial load % (*see* Note)	Rate of straining mm/min
Natural fibre	1800	2	150 ± 50
Synthetic fibre	900	1	100 max.
Note Percentage of specified minimum breaking load.			

7.2.3 The actual breaking load is to be not less than that given in an appropriate National Standard.

7.2.4 If the sample is held by grips and the break occurs within 150 mm of the grips, the test may be repeated, but not more than two tests may be made on any one coil.

7.2.5 Where difficulty is experienced in testing a sample of a completed synthetic fibre rope, LR will consider alternative methods of testing.

7.3 Identification

7.3.1 Each coil of rope is to be identified with an attached label detailing the material, construction, diameter and length.

7.4 Certification

7.4.1 A manufacturer's certificate, in accordance with *Ch 1, 3.1 General 3.1.3*, is to be issued. The certificate is to be validated by the manufacturer's representative, who is to be independent of the production process and LR.

7.4.2 Each test certificate is to include the following particulars:

- Manufacturer's name.
- Purchaser's name and order number.
- Rope type.
- Dimensions.
- Test length.
- Rate of straining.
- Breaking load.

Contents

Section

■ *Section 1* General

1.1 Scope

1.1.1 Provision is made in this Chapter for the approval by Lloyd's Register (hereinafter referred to as 'LR') of electrodes, wires, fluxes and other consumables intended for use in the welding of the following types of materials:

(a) Steel of various grades as represented by Grade A through to Grade FH69, *see Ch 11, 3 Electrodes for manual and gravity welding*.
(b) A wide range of low-temperature service steels, *see Ch 11, 3 Electrodes for manual and gravity welding*.
(c) Stainless steels including nitrogen strengthened grades and some of the duplex varieties, *see Ch 11, 8 Consumables for welding austenitic and duplex stainless steels*.
(d) Aluminium alloys, *see Ch 11, 9 Consumables for welding aluminium alloys*.

1.1.2 For this purpose, welding, consumables are categorised and subject to the special requirements of different Sections of this Chapter.

(a) Covered electrodes for manual welding and gravity welding.
(b) Combinations of wire and flux for automatic submerged-arc welding.
(c) Combinations of wire and gas for gas metal-arc welding and wires for self-shielding welding.
(d) Combinations for electro-slag and electro-gas welding.
(e) Combinations with temporary backing materials for one-side welding.
(f) Consumables for welding austenitic and duplex stainless steels.
(g) Combinations for welding aluminium.

1.2 Grading

1.2.1 Consumables for welding structural steels are graded into ten strength levels, and each of these is further subdivided into several levels in respect of notch toughness. The five basic levels of toughness are indicated by a number (1 to 5). Normal tensile strength is indicated by `N'. Higher tensile strength is indicated by `Y', and if the yield strength is higher than 375 N/mm^2 the Y is followed by a number (40 to 69), as shown in *Table 11.1.1 Welding consumable grades appropriate to structural and low temperature service steel grades*.

Table 11.1.1 Welding consumable grades appropriate to structural and low temperature service steel grades

Consumables grade	Suitable for steel grades (*see* Notes)			
1. Ship Grade Steels (*Ch 3, 2 Normal strength steels for ship and other structural applications* and *Ch 3, 3 Higher strength steels for ship and other structural applications*)				
1N	A	***AH27S***	—	—
2N	B,D	***DH27S***	—	—
3N	E	***EH27S***	—	—
1Y	A	***AH27S***	***AH32***	***AH36***
2Y	B,D	***DH27S***	***DH32***	***DH36***
3Y	E	***EH27S***	***EH32***	***EH36***
4Y	—	***FH27S***	***FH32***	***FH36***
2Y40	***AH32***	***AH36***	***AH40***	—
2Y40	***DH32***	***DH36***	***DH40***	—
3Y40	***EH32***	***EH36***	***EH40***	—
4Y40	***FH32***	***FH36***	***FH40***	—
5Y40	***FH32***	***FH36***	***FH40***	—
	—	—		
	—	—		
3Y47	—	—	***EH40***	***EH47***
	—	—		
2. High Strength Steels (*Ch 3, 10 High strength quenched and tempered steels for welded structures*) *see* Note 3				
3Y42	***AH36***	***AH40***	AH42	—
3Y42	***DH36***	***DH40***	DH42	—
4Y42	***EH36***	***EH40***	EH42	—
5Y42	***FH36***	***FH40***	FH42	—
3Y46	***AH40***	AH42	AH46	—
3Y46	***DH40***	DH42	DH46	—
4Y46	***EH40***	EH42	EH46	—
5Y46	***FH40***	FH42	FH46	—
3Y50	AH42	AH46	AH50	
3Y50	DH42	DH46	DH50	—
4Y50	EH42	EH46	EH50	—
5Y50	FH42	FH46	FH50	—
3Y55	AH50	AH55	—	—
3Y55	DH50	DH55	—	—
4Y55	EH50	EH55	—	—

5Y55	FH50	FH55	—	—
3Y62	AH55	AH62	—	—
3Y62	DH55	DH62	—	—
4Y62	EH55	EH62	—	—
5Y62	FH55	FH62	—	—
3Y69	AH62	AH69		
3Y69	DH62	DH69	—	—
4Y69	EH62	EH69	—	—
5Y69	FH62	FH69	—	—
3. Ferritic Low Temperature Service Steels (*Ch 3, 6 Ferritic steels for low temperature service*)				
$1^1/_2$Ni	$1^1/_2$Ni	—	—	—
$3^1/_2$Ni	$3^1/_2$Ni	—	—	—
5 Ni	5 Ni	—	—	—
9 Ni	9 Ni	—	—	—

Note 1. Steel grades shown in bold italic type include the equivalent (LT-xxxx) low temperature service grades referenced in *Ch 3, 6 Ferritic steels for low temperature service*.

Note 2. The Table applies to the multi-run welding techniques (i.e. m, S, M).

Note 3. Approval of consumables intended for welding high strength steels in *Ch 3, 10 High strength quenched and tempered steels for welded structures* also includes the standard ship steel grades as shown in bold italic type and equivalent low temperature service steel grades referenced in *Ch 3, 6 Ferritic steels for low temperature service*.

1.2.2 In addition to the grade, consumables are also allocated a suffix indicating the welding technique used. These are defined in the context of the following Sections of this Chapter.

1.2.3 Consumables for structural and low temperature service steels may be controlled low hydrogen and approved as such. Grade marking H15, H10 or H5 will be applied, as appropriate.

1.2.4 For joining higher strength steels, approval granted for 1Y consumables will be limited to maximum material thickness of 25 mm.

1.2.5 Test assemblies are not to be subjected to any heat treatment, except in those higher strength grades where it is considered necessary to use the welded joint in the stress relieved (tempered) condition. In those cases, the code 'sr' will be added to the approval grade.

1.2.6 Further details of grading are given in subsequent Sections of this Chapter.

1.3 Manufacture

1.3.1 The manufacturer's plant and method of production of welding consumables are to be such as to ensure reasonable uniformity in manufacture.

1.4 Approval procedures

1.4.1 Welding consumables will be approved subject to a satisfactory inspection of the works by the Surveyor for compliance with the test requirements detailed in subsequent Sections in this Chapter.

1.4.2 The test assemblies are to be prepared under the supervision of the Surveyor, and using samples selected by him. All tests are to be carried out in his presence.

1.4.3 For Charpy V-notch tests, a set of three test specimens is to be prepared and the average energy value is to comply with the requirements of subsequent Sections in this Chapter. One individual value may be less than the required average value provided that it is not less than 70 per cent of this value.

1.4.4 Where chemical analysis is required for approval, the results of the analysis are not to exceed the limit values specified in the standards or by the manufacturer, the narrower tolerances being applicable in each case.

1.4.5 LR may require, in any particular case, such additional tests or requirements as may be necessary.

1.4.6 A *List of Approved Welding Consumables* is published by LR.

1.4.7 LR is to be notified of any alteration proposed to be made in the process of manufacture subsequent to approval. Sufficient detail is to be provided to determine the need for further testing to maintain the approval.

1.4.8 Consideration will be given to alternative procedures for approval in the case of manufacturers producing consumables under the control of another manufacturer or plant already having approval of one or more products.

1.5 Annual inspection and tests

1.5.1 All establishments where approved welding consumables are manufactured, and the associated quality control procedures, are to be subjected to annual inspection. On these occasions, samples of the approved consumables are to be selected by the Surveyor and subjected to the tests detailed in subsequent Sections in this Chapter. These are to be completed and reported before the end of the one year period beginning at the initial approval date, and repeated annually so as to provide at least an average of one annual test per year.

1.6 Changes in grading

1.6.1 Changes in grading of welding consumables will be considered only at the manufacturer's request, preferably at the time of annual testing. For upgrading in connection with impact properties, and uprating in connection with tensile properties, tests from butt weld assemblies will be required in addition to the normal annual approval tests. For upgrading in connection with hydrogen testing, specific tests will be required in accordance with ISO 3690. Downgrading and downrating may be imposed by LR where tests and re-tests fail to meet the requirements of this Chapter.

1.7 Manufacturers' Quality Assurance Systems

1.7.1 As an alternative to *Ch 11, 1.5 Annual inspection and tests*, manufacturers may seek maintenance of approval based on acceptance by LR of their `in house` quality assurance system, and by regular audit of that system carried out in accordance with procedures approved by LR.

1.8 Certification

1.8.1 Each carton or package of approved consumables is to contain a certificate from the manufacturer, generally in accordance with the following: ‘The *<insert name of manufacturer>* company certifies that the composition and quality of these consumables conform with those of the consumables used in making the test pieces submitted to and approved by the approval bodies nominated on the label of this package.’

■ *Section 2* Mechanical testing procedures

2.1 Dimensions of test specimens

2.1.1 Dimensions of test pieces for deposited metal tensile tests, butt weld tensile tests, bend tests and Charpy V-notch impact test are to machined to the dimensions and tolerances detailed in *Ch 2 Testing Procedures for Metallic Materials*.

2.2 Testing procedures

2.2.1 The procedures used for all tensile and impact tests are to comply with the requirements of *Ch 2 Testing Procedures for Metallic Materials*.

2.2.2 Butt weld bend test specimens are to be tested at ambient temperature and are to be bent through an angle of 120° over a former having a diameter which relates to the thickness of the test specimen as detailed in subsequent Sections. For each pair of bend test specimens, one specimen is to be tested with the face of the weld in tension and the other with the root of the weld in tension.

2.2.3 Macro examinations are to be carried out on polished and etched specimens at a maximum magnification not exceeding x10. The examination is to ensure complete fusion, inter-run penetration and freedom of defects.

2.3 Re-testing procedures

2.3.1 Re-testing procedures are to comply with *Ch 2, 1.4 Re-testing procedures*.

■ *Section 3*
Electrodes for manual and gravity welding

3.1 Grading

3.1.1 Dependent on the results of the mechanical and other tests, approval will be allocated as one of the grades from *Table 11.1.1 Welding consumable grades appropriate to structural and low temperature service steel grades*.

3.1.2 Approval of an electrode will be given in conjunction with a welding technique indicated by a suffix `m' for manual welding, `G' for gravity or contact electrode and `p' for deep penetration electrode.

3.1.3 If the electrodes are in compliance with the requirements of the hydrogen test given in *Ch 11, 3.4 Hydrogen test*, a suffix `H15' or `H10' or `H5' will be added to the grade mark. *Table 11.3.1 Minimum low hydrogen approval requirements for manual and gravity electrodes* shows the mandatory levels of low hydrogen approval for the various approval grades.

Table 11.3.1 Minimum low hydrogen approval requirements for manual and gravity electrodes

Approval grades	Low hydrogen grade required
1 (1N), 2 (2N), 3 (3N)	NR
2Y, 3Y, 4Y	H15 (*see* Note 2)
2Y40 to 5Y40	H15
3Y47	H10
3Y42 to 5Y42	H10
3Y46 to 5Y46	H10
3Y50 to 5Y50	H10
3Y55 to 5Y55	H5
3Y62 to 5Y62	H5
3Y69 to 5Y69	H5
$1\frac{1}{2}$ Ni	H15
$3\frac{1}{2}$ Ni	H15
5 Ni	NR (*see* Note 3)
9 Ni	NR (*see* Note 3)

Note 1. NR – Not required. Approval may be obtained when requested.

Note 2. Optional in this case. If low hydrogen approval is not obtained, there is a limitation on the carbon equivalent of the steel which is permitted to be welded.

Note 3. Assumes use of an austenitic, non-transformable, filler material.

3.1.4 For each strength level, electrodes which have satisfied the requirements for a higher toughness grade are considered as complying with the requirements for a lower grade.

3.1.5 Electrodes approved for normal and higher strength levels up to and including 'Y' are also considered suitable for welding steels in the three strength levels below that for which they have been approved.

3.1.6 Electrodes approved for strength levels Y40 to Y50, but excluding Y47 are also considered suitable for welding steels in two strength levels below that for which they have been approved.

3.1.7 Electrodes approved for strength levels Y47, Y55 and above are also considered suitable for welding steels in only one strength level below that for which they have been approved.

3.1.8 The welding current used is to be within the range recommended by the manufacturer and, where an electrode is stated to be suitable for both a.c. and d.c., a.c. is to be used for the preparation of the test assemblies.

3.1.9 Where an electrode is submitted only for approval for fillet welding and to which the butt weld test provided in *Ch 11, 3.3 Butt weld test assemblies* is not considered applicable, approval tests are to consist of the fillet weld tests as given in *Ch 11, 3.5 Fillet weld test assemblies* and deposited metal tests with chemical analyses as given in *Ch 11, 3.2 Deposited metal test assemblies*.

3.2 Deposited metal test assemblies

3.2.1 The deposited metal test assemblies are to be prepared in the downhand position as shown in *Figure 11.3.1 Deposited metal test assembly*, one with 4 mm diameter electrodes and the other with 8 mm diameter electrodes, or the largest size manufactured if this is less than 8 mm diameter. If an electrode is available in one diameter only, one test assembly is sufficient. Any of the grades of steel in *Table 11.1.1 Welding consumable grades appropriate to structural and low temperature service steel grades* may be used for the preparation of these assemblies, up to a strength level which is not more than two levels above that for which approval is sought.

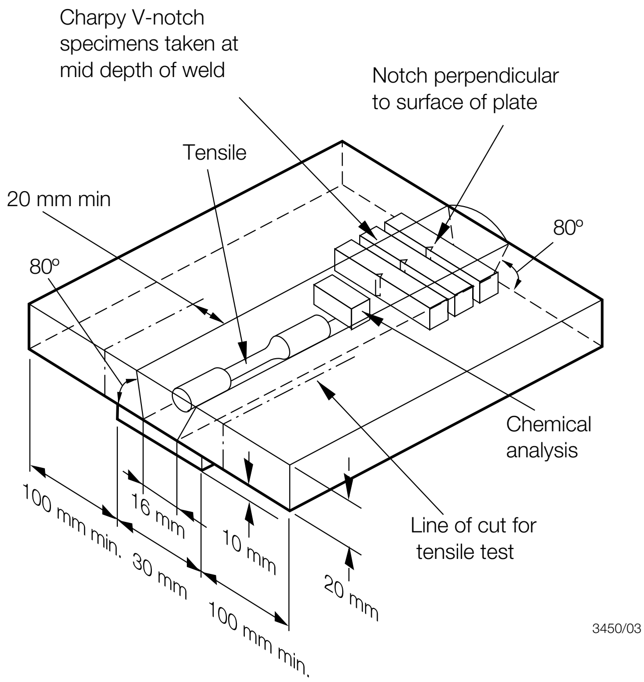


Figure 11.3.1 Deposited metal test assembly

3.2.2 For Y47 grades, as an alternative to *Figure 11.3.1 Deposited metal test assembly*, the thickness of the plate used for the test assembly may be taken as 50 mm.

3.2.3 The weld metal is to be deposited in single- or multi-run layers according to normal practice, and the direction of deposition of each layer is to alternate from each end of the plate, each run of weld metal being not less than 2 mm and not more than 4 mm thick. Between each run, the assembly is to be left in still air until it has cooled to less than 250°C, the temperature being taken in the centre of the weld, on the surface of the seam. After being welded, the test assemblies are not to be subjected to any heat treatment, except in those higher strength grades where it is considered necessary to use the welded joint in the stress-relieved (tempered) condition. In those cases, the code `sr' will be added to the approval grading.

3.2.4 The chemical analysis of the deposited weld metal in each deposited metal test assembly is to be supplied by the manufacturer and is to include the content of all significant alloying elements. The results of the analysis are not to exceed the limit values specified in the standards or by the manufacturer, the narrower tolerances being applicable in each case.

3.2.5 One tensile and three impact test specimens are to be taken from each test assembly as shown in *Figure 11.3.1 Deposited metal test assembly*. Care is to be taken that the axis of the tensile test specimen coincides with the centre of the weld and the mid-thickness of the plates. The impact test specimens are to be cut perpendicular to the weld, with their axes 10 mm from the upper surface. The notch is to be positioned in the centre of the weld and cut in the face of the test specimen perpendicular to the surface of the plate.

3.2.6 The results of all tests are to comply with the requirements of *Table 11.3.2 Requirements for deposited metal tests (covered electrodes)* as appropriate.

Table 11.3.2 Requirements for deposited metal tests (covered electrodes)

Grade (*see* Note 3)	Yield stress N/mm^2 minimum	Tensile strength N/mm^2 (*see* Note 1)	Elongation on 50 mm % minimum	Charpy V-notch impact tests	
				Test temperature °C	Average energy (*see* Note 2) J minimum
1N, 2N, 3N	305	400 – 560	22	+20, 0, –20	47
1Y, 2Y, 3Y, 4Y	375	490 – 660	22	+20, 0, –20, –40	47
2Y40, 3Y40, 4Y40, 5Y40	400	510 – 690	22	0, –20, –40, –60	47
3Y47	460	570 – 720	19	–20	53
3Y40	400	510 – 690	22	–20	47
3Y42	420	530 – 680	20	–20	47
3Y46	460	570 – 720	20	–20	47
3Y50	500	610 – 770	18	–20	50
3Y55	550	670 – 830	18	–20	55
3Y62	620	720 – 890	18	–20	62
3Y69	690	770 – 940	17	–20	69
4Y40	400	510 – 690	22	–40	47
4Y42	420	530 – 680	20	–40	47
4Y46	460	570 – 720	20	–40	47
4Y50	500	610 – 770	18	–40	50
4Y55	550	670 – 830	18	–40	55
4Y62	620	720 – 890	18	–40	62
4Y69	690	770 – 940	17	–40	69
5Y40	400	510 – 690	22	–60	47
5Y42	420	530 – 680	20	–60	47
5Y46	460	570 – 720	20	–60	47
5Y50	500	610 – 770	18	–60	50
5Y55	550	670 – 830	18	–60	55
5Y62	620	720 – 890	18	–60	62

5Y69	690	770 – 940	17	–60	69
$1^1/_2$Ni	375	460	22	–80	34
$3^1/_2$Ni	375	420	25	–100	34
5 Ni	375	500	25	–120	34
9 Ni	375	600	25	–196	34

Note 1. Single values are the minimum requirements.

Note 2. Energy values from individual impact test specimens are to comply with *Ch 11, 1.4 Approval procedures 1.4.3*.

Note 3. Grade 1Y is not applicable to SMAW consumables referenced in *Ch 11, 3 Electrodes for manual and gravity welding*

3.3 Butt weld test assemblies

3.3.1 Butt weld assemblies, as shown in *Figure 11.3.2 Butt weld test assembly*, are to be prepared for each welding position (downhand, horizontal-vertical, vertical-upward, vertical-downward, and overhead) for which the electrode is recommended by the manufacturer. In the case of electrodes for normal strength and higher strength steels (up to 355 N/mm^2 minimum specified yield strength), electrodes satisfying the requirements for downhand and vertical-upward positions will be considered as also complying with the requirements for the horizontal-vertical position. In all other cases, approval for the horizontal-vertical position will require a butt weld to be made in that position and fully tested.

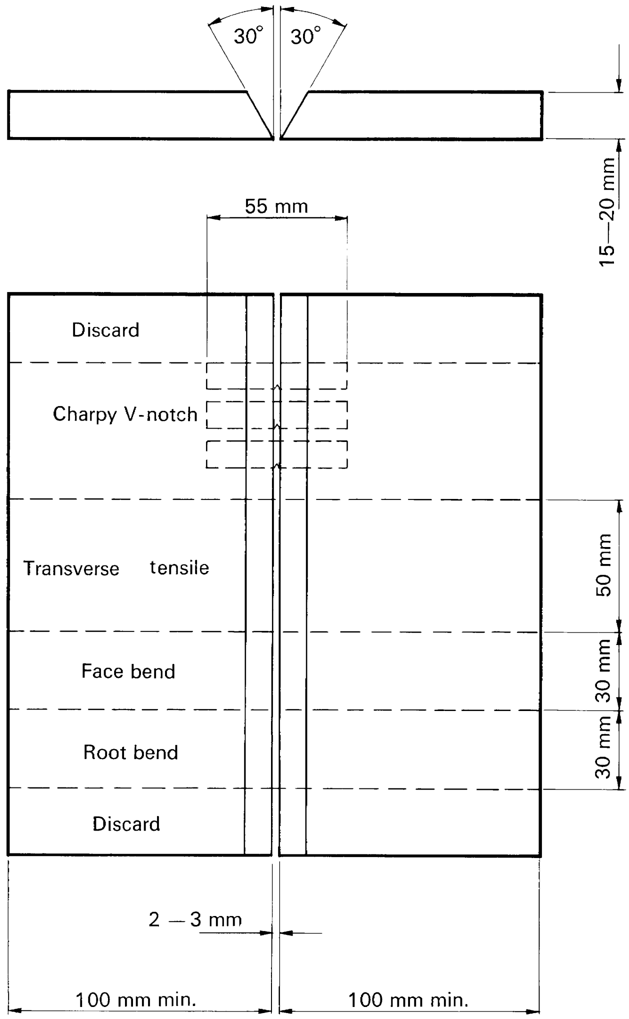


Figure 11.3.2 Butt weld test assembly

3.3.2 For Y47 grades, as an alternative to *Figure 11.3.2 Butt weld test assembly*, the thickness of the plate used for the test assembly may be taken as 50 mm.

3.3.3 Where the electrode is to be approved only in the downhand position, an additional test assembly is to be prepared in that position.

3.3.4 The grades of steel used for the preparation of the test assemblies are to be as follows:

Grade 1 (1N) electrodes	A
Grade 2 (2N) electrodes	A, B or D
Grade 3 3(N) electrodes	A, B, D or E
Grade 2Y electrodes	AH32, AH36, DH32 or DH36
Grade 3Y electrodes	AH32, AH36, DH32, DH36, EH32 or EH36
Grade 4Y electrodes	AH32 AH36, DH32, DH36, EH32, EH36, FH32 or FH36

Grade 2Y40 electrodes	AH40 or DH40
Grade 3Y40 electrodes	AH40, DH40 or EH40
Grade 4Y40 electrodes	AH40, DH40, EH40 or FH40
Grade 5Y40 electrodes	AH40, DH40, EH40 or FH40
Grade 3Y47 electrodes	EH47

Where Grade 32 higher tensile steel is used, the tensile strength is to be not less than 490 N/mm^2. The chemical composition, including the content of grain refining elements, is to be reported in all cases where higher tensile steel is used.

3.3.5 For all other grades, the steel plates used are to be selected by reference to *Table 11.1.1 Welding consumable grades appropriate to structural and low temperature service steel grades*, and are to have at least their chemical composition and tensile properties within the limits specified for that grade in *Ch 3 Rolled Steel Plates, Strip, Sections and Bars*. The strength grade used is to be the same as that for which approval is sought, and the toughness grade is to be no higher than that for which approval is also sought.

3.3.6 The test assemblies are to be made by welding together two plates of equal thickness (15 to 20 mm), not less than 100 mm in width and of sufficient length to allow the cutting out of test specimens of the prescribed number and size. The plate edges are to be prepared to form a single V-joint, the included angle between the fusion faces being 60° and the root gap 2 to 3 mm. The root face is to be 0 to 2 mm.

3.3.7 The following welding procedure is to be adopted in making the test assemblies:

Downhand (a). The first run with 4 mm diameter electrode. Remaining runs (except the last two layers) with 5 mm diameter electrodes or above according to the normal welding practice with the electrodes. The runs of the last two layers with the largest diameter of electrode manufactured or 8 mm whichever is the lesser.

Downhand (b) (where a second downhand test is required). First run with 4 mm diameter electrode. Next run with an electrode of intermediate diameter of 5 mm or 6 mm, and the remaining runs with the largest diameter of electrode manufactured or 8 mm whichever is the lesser.

Horizontal-vertical. First run with 4 mm or 5 mm diameter electrode. Subsequent runs with 5 mm diameter electrodes.

Vertical-upward and overhead. First run with 3,25 mm diameter electrode. Remaining runs with 4 mm diameter electrodes or possibly with 5 mm if this is recommended by the manufacturer for the positions concerned.

Vertical-downward. If the electrode being tested is intended for vertical welding in the downward direction, this technique is to be adopted for the preparation of the test assembly using electrode diameters as recommended by the manufacturer.

3.3.8 For all assemblies, the back sealing runs are to be made with 4 mm diameter electrodes in the welding position appropriate to each test sample, after cutting out the root run to clean metal. For electrodes suitable for downhand welding only, the test assemblies may be turned over to carry out the back sealing run.

3.3.9 Normal welding practice is to be used and, between each run, the assembly is to be left in still air until it has cooled to less than 250°C, the temperature being taken in the centre of the weld, on the surface of the seam. After being welded, the test assemblies are not to be subjected to any heat treatment, except in those higher strength grades where it is considered necessary to use the welded joint in the stress-relieved (tempered) condition. In those cases, the code `sr' will be added to the approval grading.

3.3.10 It is recommended that the welded assemblies be subjected to a radiographic examination to ascertain if there are any defects in the weld prior to the preparation of test specimens.

3.3.11 The test specimens as shown in *Figure 11.3.2 Butt weld test assembly* and *Figure 11.3.3 Butt weld test assembly position of impact test specimens* are to be prepared from each test assembly.

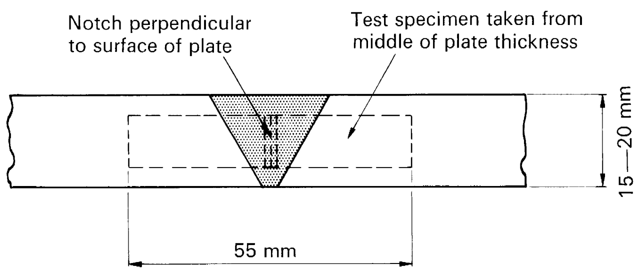


Figure 11.3.3 Butt weld test assembly position of impact test specimens

3.3.12 The results of all tensile and impact tests are to comply with the requirements of *Table 11.3.3 Requirements for butt weld tests (covered electrodes)* as appropriate. The position of fracture in the transverse tensile test is to be reported.

Table 11.3.3 Requirements for butt weld tests (covered electrodes)

Grade (*see* Note 3)	Tensile strength N/mm^2	Bend test ratio: $\frac{D}{t}$	Charpy V-notch impact tests	
			Test temperature °C	Average energy (*see* Note 1) J minimum
				All positions (*see* Note 2)
1N, 2N, 3N	400	3	+20, 0, –20	47 (34)
1Y, 2Y, 3Y, 4Y	490	3	+20, 0, –20, –40	47 (34)
2Y40, 3Y40, 4Y40, 5Y40	510	3	0, –20, –40, –60	47 (39)
3Y47	570 - 720	4	–20	53
3Y40	510	3	–20	47 (39)
3Y42	530 – 680	4	–20	47
3Y46	570 – 720	4	–20	47
3Y50	610 – 770	4	–20	50
3Y55	670 – 830	5	–20	55
3Y62	720 – 890	5	–20	62
3Y69	770 – 940	5	–20	69
4Y40	510	3	–40	47 (39)
4Y42	530 – 680	4	–40	47
4Y46	570 – 720	4	–40	47
4Y50	610 – 770	4	–40	50
4Y55	670 – 830	5	–40	55
4Y62	720 – 890	5	–40	62
4Y69	770 – 940	5	–40	69
5Y40	510	3	–60	39

5Y42	530 – 680	4	–60	47
5Y46	570 – 720	4	–60	47
5Y50	610 – 770	4	–60	50
5Y55	670 – 830	5	–60	55
5Y62	720 – 890	5	–60	62
5Y69	770 – 940	5	–60	69
$1^1/_2$Ni	490	3	–80	27
$3^1/_2$Ni	450	3	–100	27
5 Ni	540	4	–120	27
9 Ni	640	4	–196	27
Note 1. Energy values from individual impact test specimens are to comply with *Ch 11, 1.4 Approval procedures 1.4.3*.				
Note 2. Values in ( ) apply only to welds made in the vertical position with upward progression.				
Note 3. Grade 1Y is not applicable to SMAW consumables referenced in *Ch 11, 3 Electrodes for manual and gravity welding*.				

3.3.13 The bend test specimens can be considered as complying with the requirements if, after bending, no crack or other open defect exceeding 3 mm in dimensions can be seen on the outer surface.

3.4 Hydrogen test

3.4.1 The hydrogen gradings are specified in *Ch 11, 3.1 Grading 3.1.3*. The hydrogen grading required determines the method of testing permitted as shown in *Table 11.3.4 Permitted methods for obtaining low hydrogen grading*. Where ISO 3690 is used as the testing method, three test specimens are to be prepared and tested, and all three hydrogen test results must be below the maximum value for the hydrogen mark required.

Table 11.3.4 Permitted methods for obtaining low hydrogen grading

Hydrogen Grade	Permitted Method
H15	ISO 3690 (or Glycerine) (*See* Note)
H10	ISO 3690
H5	ISO 3690
Note ISO method preferred.	

3.5 Fillet weld test assemblies

3.5.1 Fillet weld assemblies as shown in *Figure 11.3.4 Fillet weld test assembly* are to be prepared for each welding position (horizontal-vertical, vertical-upward, vertical-downward or overhead) for which the electrode is recommended by the manufacturer. The grade of steel used for the test assemblies is to be as detailed in *Ch 11, 3.3 Butt weld test assemblies 3.3.4*. The length of the test assembly, *L*, is to be sufficient to allow at least the deposition of the entire length of the largest diameter electrode being tested. Where an electrode is submitted for approval of both butt and fillet welding, approval tests are to include the deposited metal tests as given in *Ch 11, 3.2 Deposited metal test assemblies*, the butt weld tests as given in *Ch 11, 3.3 Butt weld test assemblies*, and only one fillet weld test as given in subsequent paragraphs of this sub-Section welded in the horizontal-vertical position.

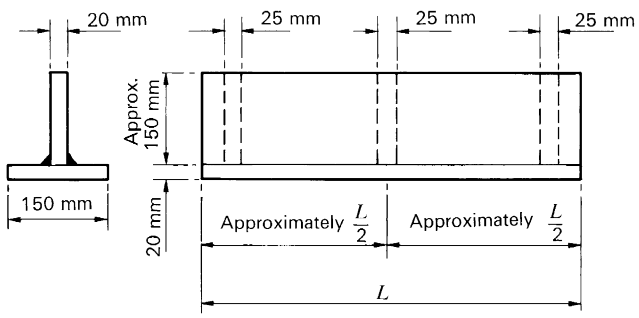


Figure 11.3.4 Fillet weld test assembly

3.5.2 For Y47 grades, as an alternative to *Figure 11.3.4 Fillet weld test assembly*, the thickness of the plate used for the test assembly may be taken as 50 mm.

3.5.3 The electrode sizes to be used are the maximum and minimum diameters recommended by the manufacturer for fillet welding. The first side is to be welded using the maximum diameter. The second side is to be welded only after the assembly has been allowed to cool below 50°C using the minimum diameter. The size of these single run fillet welds will, in general, be determined by the electrode size and the welding current employed during testing and should represent the range of fillet weld bead sizes recommended by the manufacturer.

3.5.4 Each test assembly is to be sectioned to form three macro-sections, each about 25 mm thick. These are to be examined for root penetration, satisfactory profile, freedom from cracking and reasonable freedom from porosity and slag inclusions. Any undercut is not to exceed 0,5 mm in depth. Convexity or concavity of the profile is not to exceed one-tenth of the fillet bead throat dimension. All such observations are to be reported.

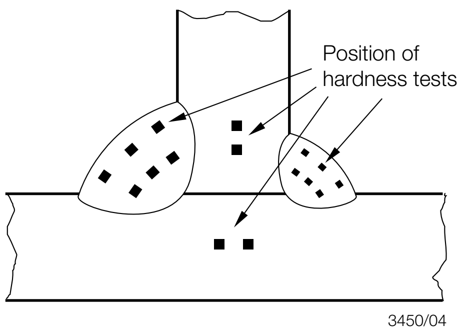


Figure 11.3.5 Hardness tests for fillet weld test assembly

3.5.5 Hardness measurements are to be made on the central macro-section only, as shown in *Figure 11.3.5 Hardness tests for fillet weld test assembly*. The results are to be reported.

3.5.6 One of the remaining sections of the assembly is to have the weld on the first side gouged or machined to facilitate breaking the fillet weld on the second side by closing the two plates together, subjecting the root of the weld to tension. On the other remaining section, the weld on the second side is to be gouged or machined and the section fractured using the same procedure. The fractured surfaces are to be examined. They are to show satisfactory penetration, freedom from cracks and reasonable freedom from porosity and this should be reported.

3.6 Electrodes designed for deep penetration welding

3.6.1 Where an electrode is designed solely for the deep penetration welding of downhand butt joints and horizontal-vertical fillets in normal tensile strength steel, only the tests detailed in *Ch 11, 3.7 Deep penetration butt weld test assemblies* and *Ch 11, 3.8 Deep penetration fillet weld test assemblies* are required for approval purposes.

3.6.2 Electrodes designed solely for the deep penetration welding technique will be approved as complying with Grade 1 requirements only and will be given the suffix `p'.

3.6.3 Where a manufacturer recommends that an electrode having deep penetrating properties can also be used for downhand butt welding of thicker plates with prepared edges, the electrode will be treated as a normal penetration electrode, and the full series of tests in the downhand position is to be carried out, together with the deep penetration tests given in *Ch 11, 3.7 Deep penetration butt weld test assemblies* and *Ch 11, 3.8 Deep penetration fillet weld test assemblies*.

3.6.4 Where a manufacturer desires to demonstrate that an electrode, in addition to its use as a normal penetration electrode, also has deep penetrating properties when used for downhand butt welding and horizontal fillet welding, the additional tests given in *Ch 11, 3.7 Deep penetration butt weld test assemblies* and *Ch 11, 3.8 Deep penetration fillet weld test assemblies* are to be carried out.

3.6.5 Electrodes approved for both normal and deep penetration welding will have the suffix 'p' added after the appropriate grade mark for normal penetration welding.

3.6.6 Where the manufacturer prescribes a different welding current and procedure for the electrode when used as a deep penetration electrode and a normal penetration electrode, the recommended current and procedure are to be used when making the test assemblies in each case.

3.7 Deep penetration butt weld test assemblies

3.7.1 Two plates of thickness equal to twice the diameter of the core of the electrode plus 2 mm are to be butt welded together with one downhand run of welding from each side. The plates are to be not less than 100 mm wide and of sufficient length to allow the cutting out of the test specimens of the correct number and size as shown in *Figure 11.3.6 Deep penetration butt weld test assembly*. Grade A steel is to be used for these test assemblies. The joint edges are to be prepared square and smooth and, after tacking, the gap is not to exceed 0,25 mm. The test assembly is to be welded using an 8 mm diameter electrode, or the largest diameter manufactured if this is less than 8 mm and the assembly is to be allowed to cool below 50°C between runs.

3.7.2 The test specimens as shown in *Figure 11.3.3 Butt weld test assembly position of impact test specimens* and *Figure 11.3.6 Deep penetration butt weld test assembly* are to be prepared from each test assembly.

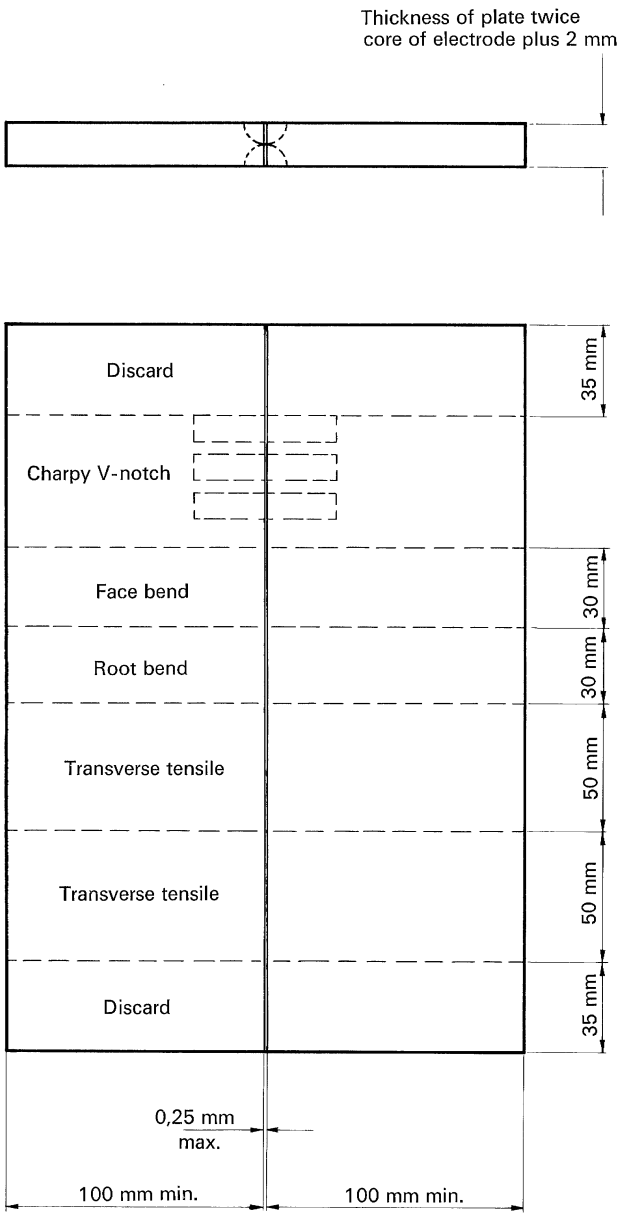


Figure 11.3.6 Deep penetration butt weld test assembly

3.7.3 The results of tensile and impact tests are to comply with the requirements of *Table 11.3.3 Requirements for butt weld tests (covered electrodes)* for Grade 1 electrodes. The position of fracture in the tensile test is to be reported. The bend test specimens are to be in accordance with *Ch 11, 3.3 Butt weld test assemblies 3.3.13*.

3.7.4 The discards at the end of the welded assemblies are to be not more than 35 mm wide. The joints of these discards are to be polished and etched and must show complete fusion and inter-penetration of the weld beads. At each cut in the test assembly, the joints are also to be examined to ensure that complete fusion has taken place.

3.8 Deep penetration fillet weld test assemblies

3.8.1 A fillet weld assembly is to be prepared as shown in *Figure 11.3.7 Deep penetration fillet weld test assembly* with plates about 12,5 mm in thickness. The welding is to be carried out with one run for each fillet with plate A in the horizontal plane during the welding operations. The length of the fillet is to be 160 mm and the gap between the plates is to be not more than 0,25 mm. Grade A steel is to be used for these test assemblies.

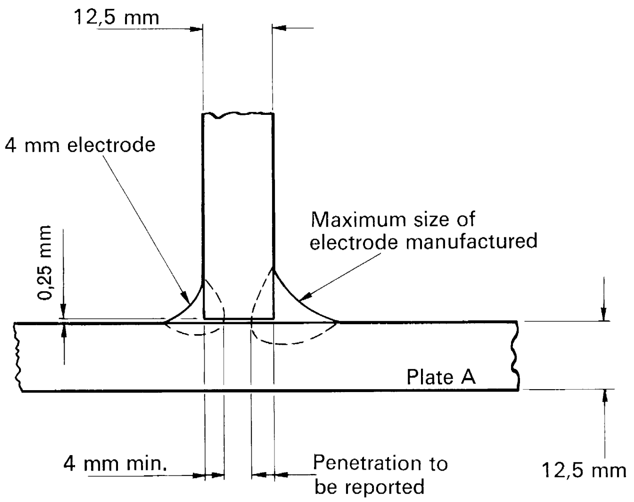


Figure 11.3.7 Deep penetration fillet weld test assembly

3.8.2 The fillet weld on one side of the assembly is to be carried out with a 4 mm diameter electrode, and that on the other side with the maximum diameter of electrode manufactured. The welding current used is to be within the range recommended by the manufacturer, and the welding is to be carried out using normal welding practice except that the assembly is to be allowed to cool below 50°C between runs.

3.8.3 The welded assembly is to be cut by sawing or machining within 35 mm of the ends of the fillet welds, and the joints are to be polished and etched. The welding of the fillet made with a 4 mm diameter electrode is to show a penetration of 4 mm (*see Figure 11.3.7 Deep penetration fillet weld test assembly*) and the corresponding penetration of the fillet made with the maximum diameter of electrode manufactured is to be reported.

3.9 Electrodes designed for gravity or contact welding

3.9.1 Approval for welding using the gravity, `G', technique is available for welding only normal strength and higher tensile steels up to and including Grade 36.

3.9.2 Where an electrode is submitted solely for approval for use in contact welding using automatic gravity or similar welding devices, deposited metal tests, butt weld tests and, where appropriate, fillet weld tests similar to those for normal manual electrodes are to be carried out using the process for which the electrode is recommended by the manufacturer.

3.9.3 Where an electrode is submitted for approval for use in contact welding using automatic gravity or similar welding devices in addition to normal manual welding, butt weld and, where appropriate, fillet weld tests, using the gravity or other contact device as recommended by the manufacturer, are to be carried out in addition to the normal approval tests.

3.10 Annual tests

3.10.1 For normal penetration electrodes, the annual tests are to consist of two deposited metal test assemblies. These are to be prepared and tested in accordance with *Ch 11, 3.2 Deposited metal test assemblies*. If an electrode is available in one diameter only, one test assembly is sufficient.

3.10.2 Where an electrode is approved solely for deep penetration welding, the annual test is to consist of one butt welded test assembly. This is to be prepared and tested in accordance with *Ch 11, 3.7 Deep penetration butt weld test assemblies*.

3.10.3 Where an electrode is approved for both normal and deep penetration welding, annual tests as detailed in *Ch 11, 3.10 Annual tests 3.10.1* and *Ch 11, 3.10 Annual tests 3.10.2* are to be carried out.

3.10.4 Where an electrode is approved solely for gravity or contact welding, the annual test is to consist of one deposited metal test assembly using the gravity or other contact device as recommended by the manufacturer.

3.10.5 Where an electrode is approved for both manual and gravity welding, annual tests as detailed in *Ch 11, 3.10 Annual tests 3.10.1* and *Ch 11, 3.10 Annual tests 3.10.4* are to be carried out.

Section 4
Wire-flux combinations for submerged-arc automatic welding

4.1 General

4.1.1 Wire-flux combinations for single and multiple electrode submerged-arc automatic welding, without the use of temporary backing, are divided into the following two categories:

- For use with the multi-run technique.
- For use with the two-run technique.

Where particular wire-flux combinations are intended for welding with both techniques, tests are to be carried out for each technique.

4.1.2 Dependent on the results of mechanical and other tests, approval will be allocated as one of the grades from *Table 11.1.1 Welding consumable grades appropriate to structural and low temperature service steel grades*.

4.1.3 The suffixes T or M will be added after the grade mark to indicate approval for the two-run technique or multi-run technique respectively.

4.1.4 Wire-flux combinations satisfying the requirements for multi-run or two-run techniques will also be approved for fillet welding in the downhand and horizontal-vertical position, subject to agreement by the manufacturer.

4.1.5 If the consumable combination is in compliance with the requirements of the hydrogen test given in *Ch 11, 3.4 Hydrogen test*, a suffix H15, H10, or H5 will be added to the grade. *Table 11.4.1 Minimum low hydrogen approval requirements for wire-flux combinations* shows the mandatory levels of low hydrogen approval for the various approval grades.

Table 11.4.1 Minimum low hydrogen approval requirements for wire-flux combinations

Approval grade	'H' grade for Multi-run	'H' grade for Two-run
1 (1N), 2 (2N), 3 (3N)	NR	NR
1Y, 2Y, 3Y, 4Y	NR	NR
2Y40 to 5Y40	H15	NR
3Y47	H10	H15
3Y42 to 5Y42	H10	H15
3Y46 to 5Y46	H10	H15
3Y50 to 5Y50	H10	H10
3Y55 to 5Y55	H5	H10
3Y62 to 5Y62	H5	H5
3Y69 to 5Y69	H5	H5
$1\frac{1}{2}$ Ni	H15	NR
$3\frac{1}{2}$ Ni	H15	NR
5 Ni (*see* Note 2)	NR	NR
9 Ni (*see* Note 2)	NR	NR

Note 1. NR – Not required. Approval can be obtained when requested.

Note 2. Assumes use of an austenitic, non-transformable, filler material.

4.1.6 For each strength level, wire-flux combinations which have satisfied the requirements for a higher toughness grade are considered as complying with the requirements for a lower grade.

4.1.7 Wire-flux combinations approved with multi-run technique for normal and higher strength levels up to and including 'Y' are also considered suitable for welding steels in the three strength levels below that for which they have been approved.

4.1.8 Wire-flux combinations approved with multi-run technique for strength levels Y40 to Y50, but excluding Y47 are also considered suitable for welding steels in two strength levels below that for which they have been approved.

4.1.9 Wire-flux combinations approved with multi-run technique for strength levels Y47, Y55 and above are also considered suitable for welding steels in only one strength level below that for which they have been approved.

4.1.10 Wire-flux combinations with two-run technique approval are not considered suitable for welding steels of any other strength level with that technique, *see Ch 11, 4.5 Approval tests for two-run technique 4.5.1*.

4.1.11 The welding current may be either a.c. or d.c. (electrode positive or negative) according to the recommendation of the manufacturer. If both a.c. and d.c. are recommended, a.c. is to be used for the tests.

4.1.12 Wire-flux combinations for multiple electrode submerged-arc welding will be subject to separate approval tests. These are to be carried out generally in accordance with the requirements of this Section.

4.1.13 Wire-flux combinations are not naturally low hydrogen in character, but for the lower strength grades of steel low hydrogen testing is not normally a requirement for approval. With higher strength steels it is more important and *Table 11.4.1 Minimum low hydrogen approval requirements for wire-flux combinations* shows the mandatory minimum low hydrogen status required for approval of wire-flux combinations.

4.2 Approval tests for multi-run technique

4.2.1 Where approval for use with the multi-run technique is requested, deposited metal and butt weld tests are to be carried out.

4.3 Deposited metal test assemblies (multi-run technique)

4.3.1 One deposited metal test assembly is to be prepared as shown in *Figure 11.4.1 Deposited metal test assembly*, using any of the grades of steel in *Table 11.1.1 Welding consumable grades appropriate to structural and low temperature service steel grades* up to a strength level which is not more than two levels above that for which approval is sought.

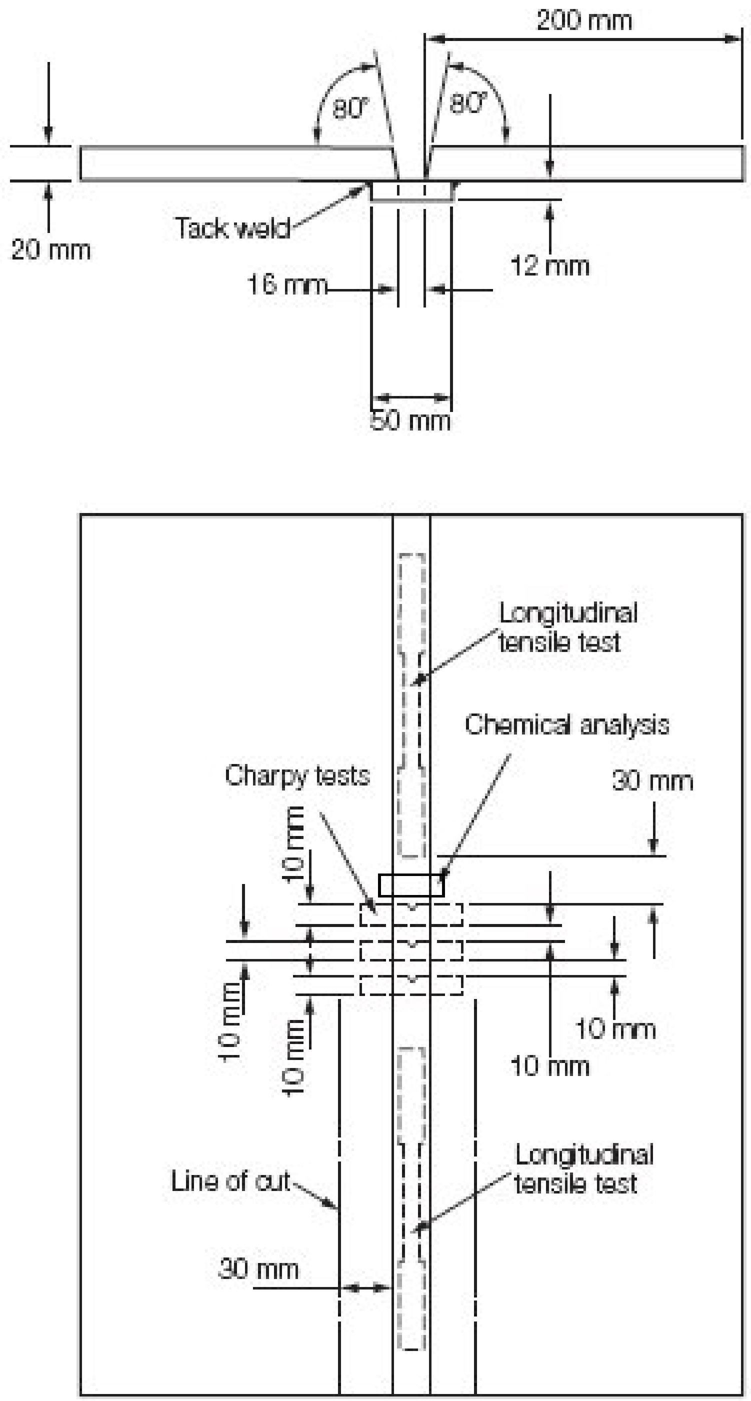


Figure 11.4.1 Deposited metal test assembly

4.3.2 For Y47 grades, as an alternative to *Figure 11.4.1 Deposited metal test assembly*, the thickness of the plate used for the test assembly may be taken as 50 mm.

4.3.3 The bevelling of the plate edges is to be carried out by machining or mechanised gas cutting. In the latter case any remaining scale is to be removed from the bevelled edges.

4.3.4 Welding is to be in the downhand position, and the direction of deposition of each run is to alternate from each end of the plate. After completion of each run, the flux and welding slag are to be removed. Between each run, the assembly is to be left in still air until it has cooled to less than 250°C, the temperature being taken in the centre of the weld, on the surface of the seam. The thickness of the layer is to be not less than the diameter of the wire nor less than 4 mm, unless it is clearly stated as part of the consumable manufacturer's published recommendations.

4.3.5 The welding conditions (amperage, voltage and rate of travel) are to be in accordance with the recommendations of the manufacturer and are to conform with normal good welding practice for multi-run welding.

4.3.6 The chemical analysis of the deposited weld metal in each test assembly is to be supplied by the manufacturer and is to include the content of all significant alloying elements. The results of the analysis are not to exceed the limit values specified in the standards or by the manufacturer, the narrower tolerances being applicable in each case.

4.3.7 Two longitudinal tensile and three impact test specimens are to be taken from each test assembly as shown in *Figure 11.4.1 Deposited metal test assembly*. Care is to be taken that the axes of the tensile test specimens coincide with the centre of the weld and the mid-thickness of the plates. The impact test specimens are to be cut perpendicular to the weld with their axes 10 mm from the upper surface. The notch is to be positioned in the centre of the weld and cut in the face of the test specimen perpendicular to the surface of the plate.

4.3.8 In those cases where two-run technique approval is also sought, only one longitudinal tensile specimen need be prepared and tested from this assembly.

4.3.9 The results of all tests are to comply with the requirements of *Table 11.4.2 Requirements for deposited metal tests (wire-flux combinations)*, as appropriate.

Table 11.4.2 Requirements for deposited metal tests (wire-flux combinations)

Grade	Yield stress N/mm^2 minimum	Tensile strength N/mm^2	Elongation on 50 mm % minimum	Charpy V-notch impact tests	
				Test temperature °C	Average energy (*see* Note) J minimum
1N, 2N, 3N	305	400 – 560	22	+20, 0, –20	34
1Y, 2Y, 3Y, 4Y	375	490 – 660	22	+20, 0, –20, –40	34
2Y40, 3Y40, 4Y40, 5Y40	400	510 – 690	22	0, –20, –40, –60	39
3Y47	460	570 – 720	19	–20	53
3Y40	400	510 – 690	22	–20	39
3Y42	420	530 – 680	20	–20	47
3Y46	460	570 – 720	20	–20	47
3Y50	500	610 – 770	18	–20	50
3Y55	550	670 – 830	18	–20	55
3Y62	620	720 – 890	18	–20	62
3Y69	690	770 – 940	17	–20	69
4Y40	400	510 – 690	22	–40	39
4Y42	420	530 – 680	20	–40	47
4Y46	460	570 – 720	20	–40	47
4Y50	500	610 – 770	18	–40	50
4Y55	550	670 – 830	18	–40	55
4Y62	620	720 – 890	18	–40	62
4Y69	690	770 – 940	17	–40	69

5Y40	400	510 – 690	22	–60	39
5Y42	420	530 – 680	20	–60	47
5Y46	460	570 – 720	20	–60	47
5Y50	500	610 – 770	18	–60	50
5Y55	550	670 – 830	18	–60	55
5Y62	620	720 – 890	18	–60	62
5Y69	690	770 – 940	17	–60	69
$1^1/_2$Ni	375	460	22	–80	34
$3^1/_2$Ni	375	420	25	–100	34
5 Ni	375	500	25	–120	34
9 Ni	375	600	25	–196	34
Note Energy values from individual impact test specimens are to comply with *Ch 11, 1.4 Approval procedures 1.4.3*.					

4.4 Butt weld test assemblies (multi-run technique)

4.4.1 One butt weld test assembly is to be prepared as shown in *Figure 11.4.2 Butt weld test assembly (multi-run technique)*.

4.4.2 The grade of steel used for the preparation of the test assembly are to be as follows:

Grade 1 wire-flux combination	A
Grade 2 wire-flux combinations	A, B or D
Grade 3 wire-flux combinations	A, B, D or E
Grade 1Y wire-flux combination	AH32 or AH36
Grade 2Y wire-flux combinations	AH32, AH36, DH32 or DH36
Grade 3Y wire-flux combinations	AH32, AH36, DH32, DH36, EH32 or EH36
Grade 4Y wire-flux combinations	AH32, AH36, DH32, DH36, EH32, EH36, FH32 or FH36
Grade 2Y40 wire-flux combination	AH40 or DH40
Grade 3Y40 wire-flux combinations	AH40, DH40 or EH40
Grade 4Y40 wire-flux combinations	AH40, DH40, EH40 or FH40
Grade 5Y40 wire-flux combinations	AH40, DH40, EH40 or FH40
Grade 3Y47 wire-flux combinations	EH47

Where Grade 32 higher tensile steel is used, the tensile strength is to be not less than 490 N/mm^2. The chemical composition, including the content of grain refining elements, is to be reported in all cases where higher tensile steel is used.

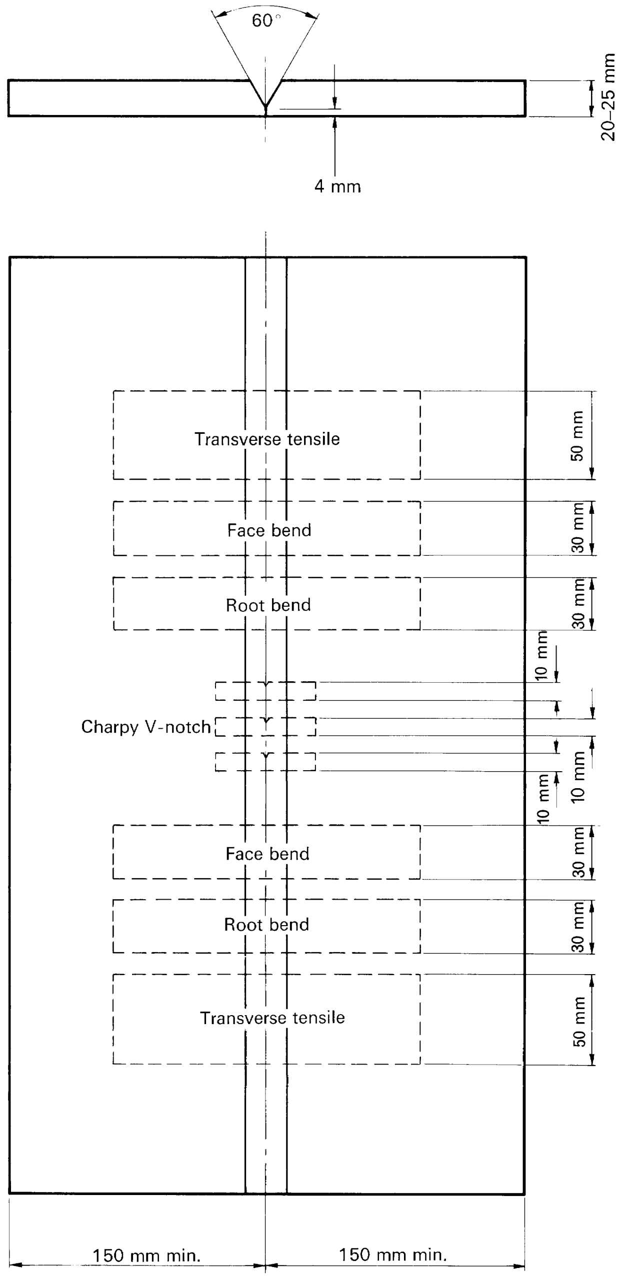


Figure 11.4.2 Butt weld test assembly (multi-run technique)

4.4.3 For all other grades, the steel plates used are to be selected by reference to *Table 11.1.1 Welding consumable grades appropriate to structural and low temperature service steel grades*, and are to have at least their chemical composition and tensile properties within the limits specified for that grade in *Ch 3 Rolled Steel Plates, Strip, Sections and Bars*. The strength grade used is to be the same as that for which approval is sought, and the toughness grade is to be no higher than that for which approval is also sought.

4.4.4 The plate edges are to be prepared to form a single V-joint, the included angle between the fusion faces being 60° and the root face being 4 mm. The bevelling of the plate edges is to be carried out by machining or mechanised gas cutting. In the latter case, any remaining scale is to be removed from bevelled edges.

4.4.5 Welding is to be carried out in the downhand position by the multi-run technique, and the welding conditions are to be the same as those adopted for the deposited metal test assembly. The back sealing run is to be applied in the downhand position after cutting out the root run to clean metal.

4.4.6 It is recommended that the welded assembly be subjected to a radiographic examination to ascertain if there are any defects in the weld prior to the preparation of test specimens.

4.4.7 The test specimens as shown in *Figure 11.3.3 Butt weld test assembly position of impact test specimens* and *Figure 11.4.2 Butt weld test assembly (multi-run technique)* are to be prepared from each test assembly.

4.4.8 The results of all tensile and impact tests are to comply with the requirements of *Table 11.4.3 Requirements for butt weld tests (wire-flux combinations)*, as appropriate. The position of fracture of the transverse tensile test is to be reported.

Table 11.4.3 Requirements for butt weld tests (wire-flux combinations)

Grade	Tensile strength N/mm^2	Bend test ratio: $\frac{D}{t}$	Charpy V-notch impact tests	
			Test temperature °C	Average energy (*see* Notes 1 and 2) J minimum
1N, 2N, 3N	400	3	+20, 0, –20	34
1Y, 2Y, 3Y, 4Y	490	3	+20, 0, –20, –40	34
2Y40, 3Y40, 4Y40, 5Y40	510	3	0, –20, –40, –60	39
3Y47	570 – 720	4	–20	53
3Y40	510	3	–20	39
3Y42	530 – 680	4	–20	47 (41)
3Y46	570 – 720	4	–20	47
3Y50	610 – 770	4	–20	50
3Y55	670 – 830	5	–20	55
3Y62	720 – 890	5	–20	62
3Y69	770 – 940	5	–20	69
4Y40	510	3	–40	39
4Y42	530 – 680	4	–40	47 (41)
4Y46	570 – 720	4	–40	47
4Y50	610 – 770	4	–40	50
4Y55	670 – 830	5	–40	55
4Y62	720 – 890	5	–40	62
4Y69	770 – 940	5	–40	69
5Y40	510	3	–60	39
5Y42	530 – 680	4	–60	47 (41)
5Y46	570 – 720	4	–60	47
5Y50	610 – 770	4	–60	50
5Y55	670 – 830	5	–60	55
5Y62	720 – 890	5	–60	62
5Y69	770 – 940	5	–60	69
$1^1/_2$Ni	490	3	–80	27

$3^1/_2$Ni	450	3	–100	27
5 Ni	540	4	–120	27
9 Ni	640	4	–196	27
Note 1. Energy values from individual impact test specimens are to comply with *Ch 11, 1.4 Approval procedures 1.4.3*.				
Note 2. Values in ( ) apply only to two-run technique impact test specimens.				

4.4.9 The bend test specimens can be considered as complying with the requirements if, after bending, no cracks or other open defects exceeding 3 mm in dimension can be seen on the outer surface.

4.5 Approval tests for two-run technique

4.5.1 Where approval for use with the two-run technique is requested, two butt weld test assemblies are to be prepared and tested using plates of the strength level for which approval is required. Each strength level requires separate approval.

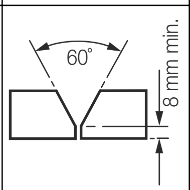
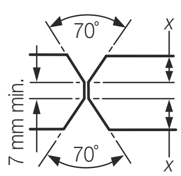
4.5.2 Two welded assemblies are to be made from a pair of plates of matching thicknesses. The thickness of the thicker pair of plates will be the maximum for which the approval is valid. The second assembly is to be welded from plates having approximately half of the thickness of the first assembly.

4.6 Butt weld test assemblies (two-run technique)

4.6.1 The grade of steel used for the preparation of the test assemblies is not to be of any higher grade (impact toughness) than that for which approval is required. The chemical composition, including the content of grain refining elements, and the strength properties of the plates used, are to be reported.

4.6.2 The maximum diameter of wire and the edge preparation to be used are to be in accordance with *Table 11.4.4 Butt weld assembly preparation*. Small deviations in the edge preparation may be allowed if requested by the manufacturer. The bevelling of the plate edges is to be performed by machining or mechanized gas cutting. In the latter case, any remaining scale is to be removed from the bevelled edges. The root gap should not exceed 0,7 mm.

Table 11.4.4 Butt weld assembly preparation

Plate thickness mm	Recommended diameter	Maximum diameter of wire mm
12,5		5
20–25		6
35–40		7

4.6.3 Each butt weld is to be welded in two runs, one from each side, using amperages, voltages and travel speeds in accordance with the recommendations of the manufacturer and normal good welding practice. After completion of the first run, the flux and welding slag are to be removed and the assembly is to be left in still air until it has cooled to less than 100°C, the temperature being taken in the centre of the weld, on the surface of the seam.

4.6.4 It is recommended that the butt weld assemblies be subjected to radiographic examination to ascertain if there are any defects in the weld prior to the preparation of test specimens.

4.6.5 The test specimens, as shown in *Figure 11.4.3 Butt weld test assembly (two-run technique)* and *Figure 11.4.4 Butt weld test assembly (two-run technique): position of impact test specimens*, are to be prepared from each test assembly, except as detailed in *Ch 11, 4.6 Butt weld test assemblies (two-run technique) 4.6.8*. The edges of two of the discards are to be polished and etched, and must show complete fusion and inter-run penetration of the welds. At each cut in the test assembly, the edges are also to be examined to ensure that complete fusion has taken place.

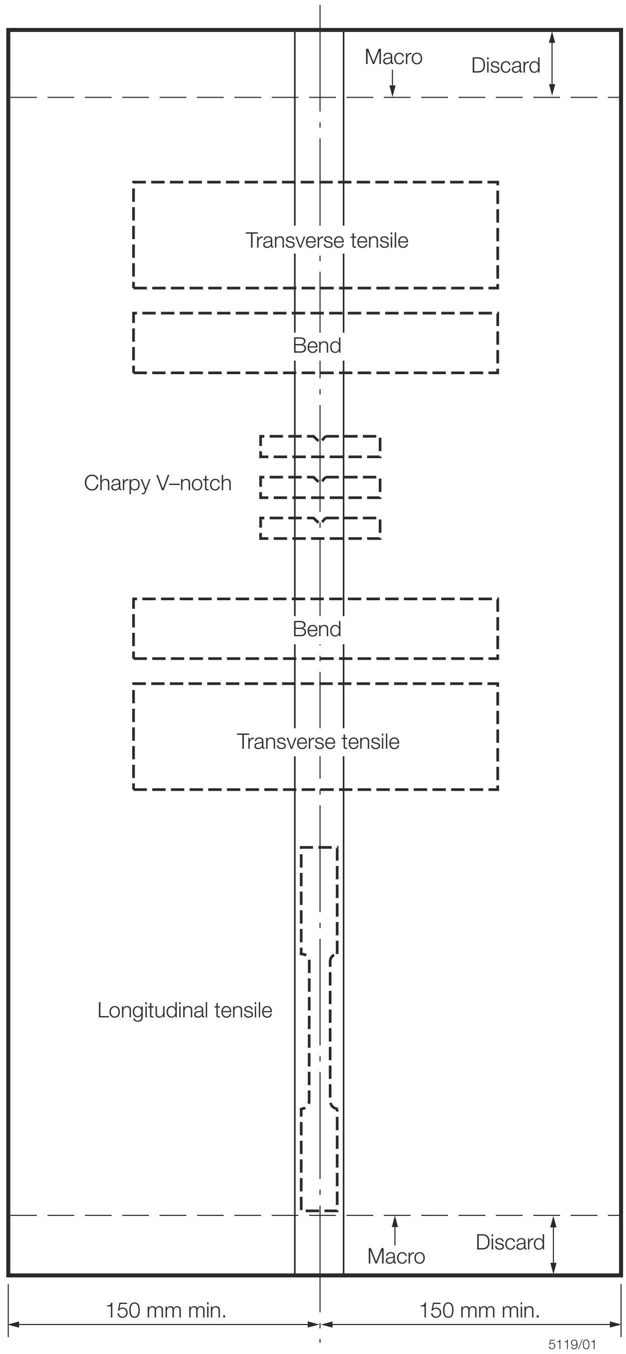


Figure 11.4.3 Butt weld test assembly (two-run technique)

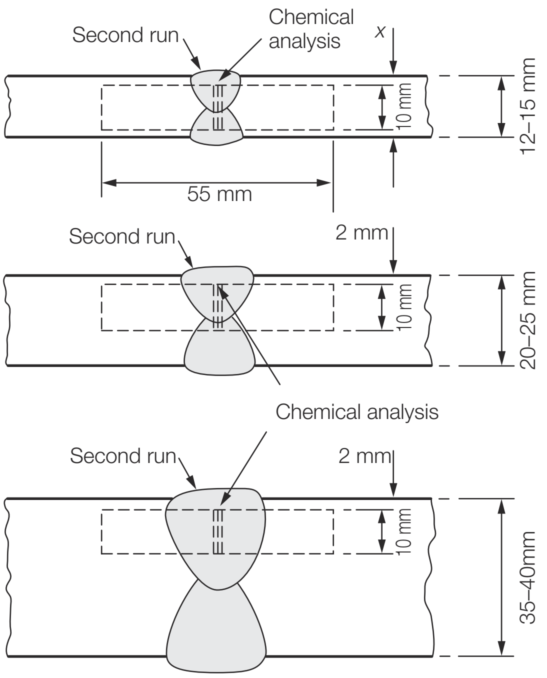


Figure 11.4.4 Butt weld test assembly (two-run technique): position of impact test specimens

4.6.6 The results of transverse tensile and impact tests are to comply with the requirements of *Table 11.4.3 Requirements for butt weld tests (wire-flux combinations)* as appropriate. The position of fracture of the transverse tensile tests is to be reported.

4.6.7 The bend test specimens can be considered as complying with the requirements if, after bending, no crack or other open defects exceeding 3 mm in dimensions can be seen on the outer surface. One of the specimens from each assembly is to be tested with the side first welded in tension, and the second specimen with the other side in tension.

4.6.8 The longitudinal tensile specimen shown in *Figure 11.4.3 Butt weld test assembly (two-run technique)* is to be prepared from the thicker assembly, even in those cases where multi-run technique approval is also sought. This test specimen is to be machined to the dimensions shown in *Ch 11, 2.1 Dimensions of test specimens 2.1.1* and the longitudinal axis is to coincide with the centre of the weld about 7 mm below the plate surface on the side from which the second run is made. The test specimen may be given a hydrogen release treatment in accordance with *Ch 11, 2.1 Dimensions of test specimens 2.1.1*. The results of this test are to comply with the requirements of *Table 11.4.2 Requirements for deposited metal tests (wire-flux combinations)*.

4.6.9 The chemical analysis of the weld metal of the second run in each assembly is to be determined and reported. This is to include the content of all significant elements. The results of the analysis are not to exceed the limit values specified in the standards or by the manufacturer, the narrower tolerances being applicable in each case.

4.7 Annual tests

4.7.1 Annual tests are to consist of at least the following:

(a) For wire-flux combinations approved for the multi-run technique, one deposited metal test assembly.
(b) For wire-flux combinations approved for the two-run technique, one butt weld test assembly using plate material 20 to 25 mm in thickness. For Y47, the thickness of plate material may be taken as 50 mm.

4.7.2 The deposited metal assemblies are to be prepared and tested in accordance with *Ch 11, 4.3 Deposited metal test assemblies (multi-run technique)*, except that only one longitudinal tensile, three impact test specimens and a chemical analysis are required.

4.7.3 The butt weld test assemblies are to be prepared and tested in accordance with *Ch 11, 4.6 Butt weld test assemblies (two-run technique)*, except that only one transverse tensile, two bend, three impact test specimens and a chemical analysis are required. One longitudinal tensile test specimen is also to be prepared where the wire-flux combination is approved solely for the two-run technique.

4.7.4 Where a wire-flux combination is approved for welding a range of steels with different specified minimum strength levels, steel of the highest strength approved is to be used for the preparation of the butt weld assembly required by *Ch 11, 4.7 Annual tests 4.7.1*.

■ *Section 5*
Wires and wire-gas combinations for manual, semi-automatic and automatic welding

5.1 General

5.1.1 Wire-gas combinations and flux-cored or flux-coated wires (for use with or without a shielding gas) are divided into the following categories for the purposes of approval testing:

(a) For use in manual multi-run welding with the inert gas tungsten arc welding process (GTAW).
(b) For use in semi-automatic multi-run metal arc welding.
(c) For use in single electrode multi-run automatic metal arc and GTAW welding.
(d) For use in single electrode two-run automatic metal arc and GTAW welding.

5.1.2 The term `manual' is used to describe the technique where the gas-shielded tungsten arc torch is held in one hand and the filler is added separately by the other hand.

5.1.3 The term `semi-automatic' is used to describe processes in which the weld is made manually by a welder holding a gun through which the wire is continuously fed.

5.1.4 In the GTAW process, `automatic' refers to the fully mechanized control and application of both torch and separate filler wire.

5.1.5 Dependent on the results of mechanical and other tests, approval will be allocated as one of the grades from *Table 11.1.1 Welding consumable grades appropriate to structural and low temperature service steel grades*.

5.1.6 A suffix S will be added after the grade mark to indicate approval for semi-automatic multi-run welding.

5.1.7 For wires intended for automatic welding, the suffixes T or M will be added after the grade mark to indicate approval for two-run or multi-run welding techniques, respectively.

5.1.8 For wires intended for both semi-automatic and automatic welding, the suffixes will be added in combination.

5.1.9 Solid wire-gas combinations are considered naturally low hydrogen in character and qualify for `H15' approval without testing. This is not so for cored wires and continuous coated wires which must be tested if there is a need for low hydrogen approval. For the lower strength grades of steel, low hydrogen testing is not normally a requirement for approval. With higher strength steels, it is more important and *Table 11.5.1 Minimum low hydrogen approval requirements for wires and wire-gas combinations* shows the mandatory minimum low hydrogen status required for approval of wire-gas combinations.

5.1.10 The testing methods to be used for low hydrogen approval are to be in accordance with *Ch 11, 3.4 Hydrogen test*, modified to use the manufacturer's recommended welding conditions and adjusting the deposition rate to give a weld deposit weight per sample similar to that deposited when using manual electrodes.

5.1.11 Where applicable, the approved combination will name either the specific gas composition or its trade name, but in either case the composition of the shielding gas is to be reported. Unless otherwise agreed, additional approval tests are required when a shielding gas is used other than that used for the original approval tests. However a wire and gas combination approved with an argon/carbon dioxide shielding gas where the carbon dioxide is between 15-25 per cent is also approved for other combinations of argon/carbon dioxide, provided the carbon dioxide content is within the range 15-25 per cent. The range of approval is limited to ferritic consumables in solid wire, flux cored and coated wire forms and subject to the agreement of the consumable manufacturer and LR.

5.1.12 Wires and wire-gas combinations for multiple electrode automatic welding will be subject to separate approval tests. Any proposals are to be submitted for consideration.

5.1.13 Wires and wire-gas combinations approved with multi-run technique for normal and higher strength levels up to and including 'Y' are also considered suitable for welding steels in the three strength levels below that for which they have been approved.

5.1.14 Wires and wire-gas combinations approved with multi-run technique for strength levels Y40 to Y50, but excluding Y47 are also considered suitable for welding steels in two strength levels below that for which they have been approved.

5.1.15 Wires and wire-gas combinations approved with multi-run technique for strength levels Y47, Y55 and above are also considered suitable for welding steels in only one strength level below that for which they have been approved.

5.1.16 Wires and wire-gas combinations with two-run technique approval are not considered suitable for welding steels of any other strength level with that technique, *see Ch 11, 5.4 Approval tests for two-run automatic welding 5.4.1*.

Table 11.5.1 Minimum low hydrogen approval requirements for wires and wire-gas combinations

Approval grades	'H' grade for m and S techniques	'H' grade for M technique	'H' grade for T technique
1 (1N), 2 (2N), 3 (3N)	NR	NR	NR
1Y, 2Y, 3Y, 4Y	H15 (*see* Note 2)	NR	NR
2Y40 to 5Y40	H15	H15	NR
3Y47	H10	H10	H10
3Y42 to 5Y42	H10	H10	H15
3Y46 to 5Y46	H10	H10	H15
3Y50 to 5Y50	H10	H10	H10
3Y55 to 5Y55	H5	H5	H10
3Y62 to 5Y62	H5	H5	H5
3Y69 to 5Y69	H5	H5	H5
$1\frac{1}{2}$ Ni	H15	H15	NR
$3\frac{1}{2}$ Ni	H15	H15	NR
5 Ni	NR (see Note 3)	NR	NR
9 Ni	NR (see Note 3)	NR	NR

Note 1. NR – Not required. Approval may be obtained when requested.

Note 2. Optional in this case. If low hydrogen approval is not obtained, there is a limitation on the carbon equivalent of the steel which is permitted to be welded.

Note 3. Assumes use of an austenitic, non-transformable, filler material.

5.2 Approval tests for manual and semi-automatic multi-run welding

5.2.1 Approval tests for manual (GTAW) and semi-automatic multi-run welding are to be carried out generally in accordance with the requirements of *Ch 11, 3 Electrodes for manual and gravity welding*, except as required by *Ch 11, 5.2 Approval tests for manual and semi-automatic multi-run welding*, using the respective technique for the preparation of all test assemblies.

5.2.2 Two deposited metal test assemblies are to be prepared in the downhand position as shown in *Figure 11.3.1 Deposited metal test assembly*, one using the smallest diameter, and the other using the largest diameter of wire for which approval is required. Where only one diameter is manufactured, only one deposited metal assembly is to be prepared.

5.2.3 For Y47 grades, as an alternative to *Figure 11.3.1 Deposited metal test assembly*, the thickness of the plate used for the test assembly may be taken as 50 mm.

5.2.4 The weld metal is to be deposited according to the practice recommended by the manufacturer, and the thickness of each layer of weld metal is to be between 2 mm and 6 mm, unless it is clearly stated as part of the consumable manufacturer's published recommendations.

5.2.5 The chemical analysis of the deposited weld metal in each test assembly is to be supplied by the manufacturer and is to include the content of all significant alloying elements. The results of the analysis are not to exceed the limit values specified in the standards or by the manufacturer, the narrower tolerances being applicable in each case.

5.2.6 Butt weld assemblies as shown in *Figure 11.3.2 Butt weld test assembly* are to be prepared for each welding position for which the wire is to be approved. In the case of approvals for normal and higher strength steels (up to 355 N/mm^2 minimum specified yield strength), tests satisfying the requirements in both the downhand and vertical-upward positions will be considered as having also satisfied the requirements for the horizontal-vertical position. In all other cases, approval in the horizontal-vertical position will require a butt weld to be made in that position and be fully tested.

5.2.7 The downhand assembly is to be welded using, for the first run, wire of the smallest diameter to be approved and, for the remaining runs, wire of the largest diameter to be approved.

5.2.8 Where approval is requested only in the downhand position, an additional butt weld assembly is to be prepared in that position using, if possible, wires of different diameter from those required by *Ch 11, 5.2 Approval tests for manual and semi-automatic multi-run welding 5.2.7*. If only one wire diameter is to be approved, this second downhand butt weld should be made using either larger or smaller beads than the first assembly.

5.2.9 The butt weld assemblies, in positions other than downhand, are to be welded using, for the first run, wire of the smallest diameter to be approved, and for the remaining runs, the largest diameter of wire recommended by the manufacturer for the position concerned.

5.2.10 Fillet weld test assemblies as detailed in *Ch 11, 3.5 Fillet weld test assemblies* are to be prepared, examined and tested.

5.2.11 Low hydrogen approval tests are to be carried out if required by *Ch 11, 5.1 General 5.1.9*.

5.2.12 Test specimens from each assembly are to be prepared and tested in accordance with the requirements of *Ch 11, 3.2 Deposited metal test assemblies* and *Ch 11, 3.3 Butt weld test assemblies*.

5.3 Approval tests for multi-run automatic welding

5.3.1 Approval tests for multi-run automatic welding are to be carried out generally in accordance with the requirements of *Ch 11, 4 Wire-flux combinations for submerged-arc automatic welding*, except as required by *Ch 11, 5.3 Approval tests for multi-run automatic welding*, using the multi-run automatic welding technique for the preparation of all test assemblies.

5.3.2 One deposited metal test assembly is to be prepared as shown in *Figure 11.4.1 Deposited metal test assembly*. Welding is to be as detailed in *Ch 11, 4.3 Deposited metal test assemblies (multi-run technique) 4.3.4*, except that the thickness of each layer is to be not less than 3 mm, unless it is clearly stated as part of the consumable manufacturer's published recommendations.

5.3.3 For Y47 grades, as an alternative to *Figure 11.4.1 Deposited metal test assembly*, the thickness of the plate used for the test assembly may be taken as 50 mm.

5.3.4 One butt weld test assembly is to be prepared as shown in *Figure 11.4.2 Butt weld test assembly (multi-run technique)* for each welding position to be approved for the automatic multi-run technique.

5.3.5 Test specimens from each test assembly are to be prepared and tested in accordance with the requirements of *Ch 11, 4 Wire-flux combinations for submerged-arc automatic welding* for multi-run submerged-arc automatic welding.

5.3.6 Low hydrogen approval tests are to be made if required by *Ch 11, 5.1 General 5.1.9*.

5.3.7 At the discretion of LR, wires approved for semi-automatic welding in the downhand position may also be approved without additional tests, for use in multi-run automatic welding.

5.4 Approval tests for two-run automatic welding

5.4.1 Approval tests for two-run automatic welding are to be carried out generally in accordance with the requirements of *Ch 11, 4 Wire-flux combinations for submerged-arc automatic welding*, except as required by *Ch 11, 5.4 Approval tests for two-run automatic welding*, using the two-run automatic welding technique for the preparation of all test assemblies. Two butt weld test assemblies are to be prepared and tested using plates of the strength level for which approval is required. Each strength level requires separate approval.

5.4.2 Two butt weld test assemblies are to be prepared generally as detailed in *Ch 11, 4.5 Approval tests for two-run technique* and *Ch 11, 4.6 Butt weld test assemblies (two-run technique)* using plates 12 to 15 mm and 20 to 25 mm in thickness.

5.4.3 If approval is requested for welding plate thicker than 25 mm, one assembly is to be prepared using plates approximately 20 mm in thickness and the other using plates of the maximum thickness for which approval is requested.

5.4.4 The edge preparation of the test assemblies is to be as shown in *Figure 11.5.1 Normal edge preparation for two-run butt weld test assemblies*. Small deviations in edge preparation may be allowed, if these form part of the consumable manufacturer's recommendations. For assemblies using plates over 25 mm in thickness, the edge preparation is to be reported for information.

5.4.5 The diameters of wires used are to be in accordance with the recommendations of the manufacturer and are to be reported.

5.4.6 Test specimens from each butt weld assembly are to be prepared and tested in accordance with the requirements of *Ch 11, 4 Wire-flux combinations for submerged-arc automatic welding* for two-run submerged-arc automatic welding.

5.4.7 The weld metal chemical analysis is to be reported as in *Ch 11, 4.6 Butt weld test assemblies (two-run technique) 4.6.9*. The results of the analysis are not to exceed the limit values specified in the standards or by the manufacturer, the narrower tolerances being applicable in each case.

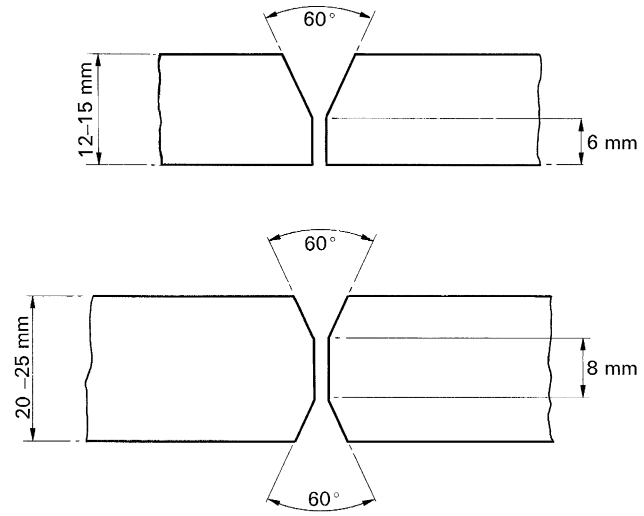


Figure 11.5.1 Normal edge preparation for two-run butt weld test assemblies

5.5 Annual tests

5.5.1 Annual tests are to consist of at least the following:

(a) Wires approved for manual welding or semi-automatic welding or either of these combined with approval for automatic multi-run welding:

one deposited metal test assembly prepared in accordance with *Ch 11, 5.2 Approval tests for manual and semi-automatic multi-run welding* using a wire of diameter within the approved range.

(b) Wire approved for automatic multi-run welding:

one deposited metal test assembly prepared in accordance with *Ch 11, 5.3 Approval tests for multi-run automatic welding* using a wire of diameter as stated in (a).

(c) Wires approved for two-run automatic welding:

one butt weld test assembly prepared in accordance with *Ch 11, 5.4 Approval tests for two-run automatic welding* using plates 20 to 25 mm in thickness or the maximum approved thickness. The diameter of wire used is to be reported.

Section 6
Consumables for use in electro-slag and electro-gas welding

6.1 General

6.1.1 The requirements for the approval of consumables used for electro-slag or electro-gas welding (including consumable nozzles, where applicable) are generally as detailed in *Ch 11, 4 Wire-flux combinations for submerged-arc automatic welding* for two-run submerged-arc welding consumables, except as otherwise detailed in this Section.

6.1.2 For each grade, approval may be restricted for use with specific compositional types of steel. For Grades 1Y, 2Y, 3Y, 4Y, 2Y40, 3Y40 and 4Y40 this will normally be in respect of the grain refining element content, and tests on niobium grain refined steel will normally qualify for use also on steels treated with aluminium or vanadium or combinations of these elements.

6.1.3 Superscript numbers are applied to the 'Y' of higher strength steel consumables, e.g. $2Y^1$, to indicate the type of parent steel for which approval is applicable as follows:

Y^1	approval Grade for higher strength steel is limited to parent steel which has been treated only with aluminium.
Y^2	approval Grade for higher strength steel is appropriate to niobium-treated steels, whether aluminium treated or not. It also covers steels treated only with aluminium.

6.1.4 Each strength level requires separate approval involving the welding and testing of two butt weld assemblies of different thickness. The greater thickness will determine the maximum approved thickness.

6.2 Butt weld test assemblies

6.2.1 Two butt weld test assemblies are to be prepared, one with plates 20 to 25 mm in thickness and the other with plates 35 to 40 mm in thickness. The steel used is not to be of any higher grade (impact toughness) than that for which approval is required. The limitations of *Ch 11, 6.1 General 6.1.2* need to be considered in this Section. The chemical composition of the plate, including the content of grain refining elements, is to be reported.

6.2.2 The welding conditions and the edge preparation adopted are to be in accordance with the recommendations of the manufacturer and are to be reported in detail. The manufacturer's maximum recommended gap between plates is to be used in making the test assemblies.

6.2.3 It is recommended that the assemblies are subjected to radiographic examination to identify any defects before the preparation of any test specimens.

6.2.4 Test specimens as follows, and as shown in *Figure 11.6.1 Butt weld test assembly for electro-slag or electro-gas welding*, are to be prepared from each test assembly:

(a) Two longitudinal tensile test specimens.
(b) Two transverse tensile test specimens.
(c) Two bend test specimens.
(d) Two macro-sections.
(e) Two sets of three impact test specimens notched in accordance with *Figure 11.6.2 Position of Charpy V-notch impact test specimens*.

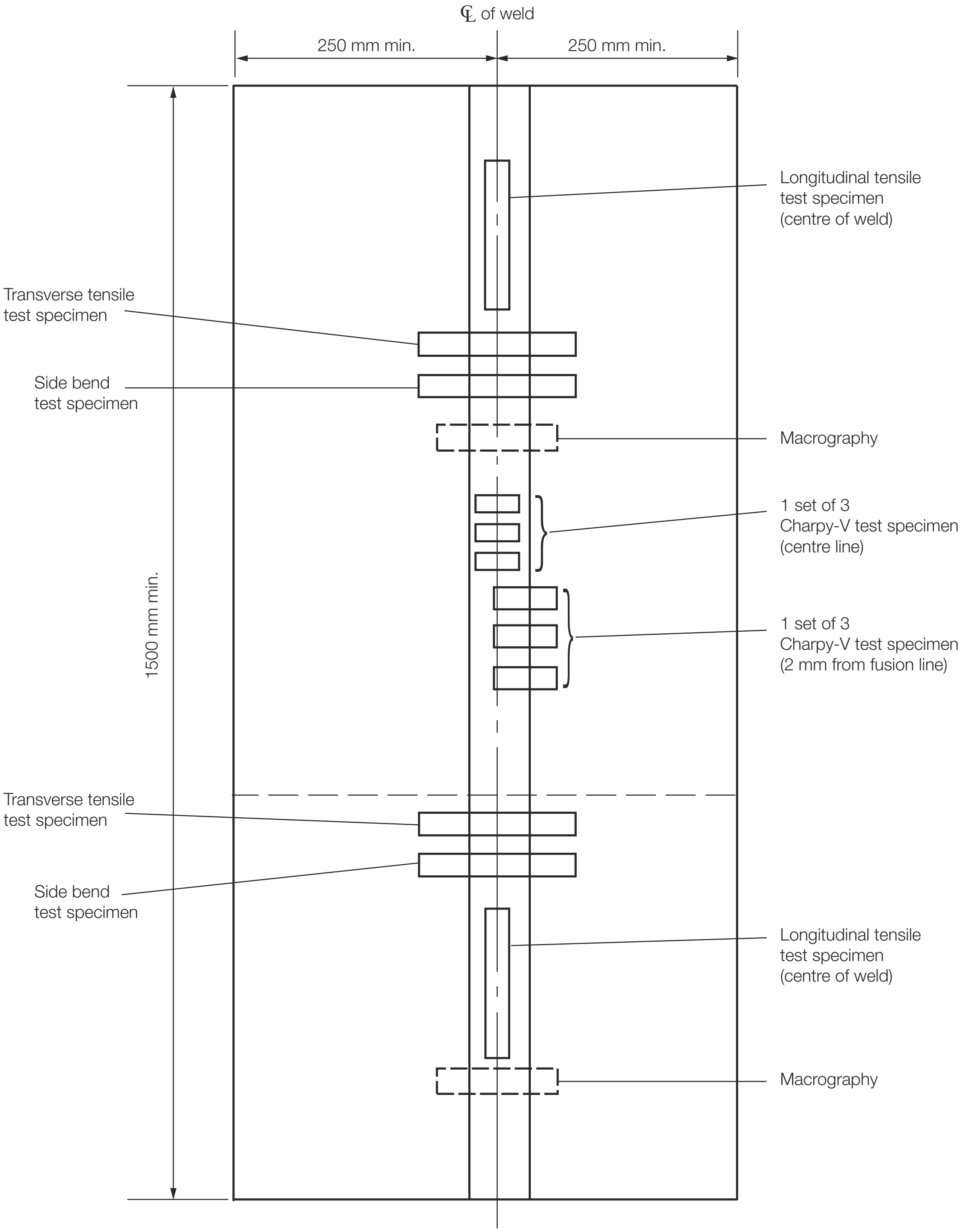


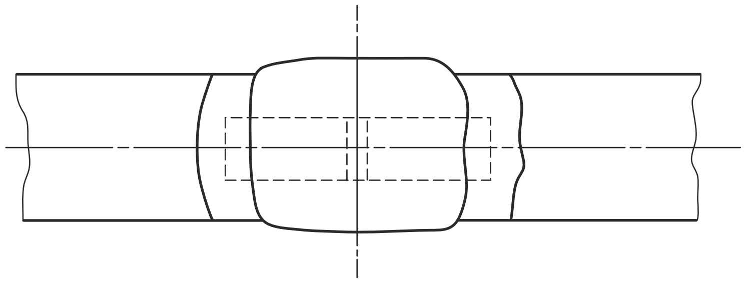
Figure 11.6.1 Butt weld test assembly for electro-slag or electro-gas welding

6.2.5 The chemical analysis of the weld metal in each assembly is to be determined and reported. This is to be supplied by the manufacturer and is to include the content of all significant elements. The results of the analysis are not to exceed the limit values specified in the standards or by the manufacturer, the narrower tolerances being applicable in each case.

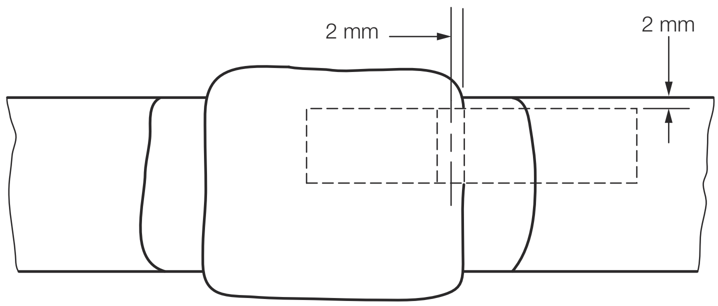
6.2.6 The results of all transverse tensile and impact tests are to comply with the requirements given in *Table 11.4.3 Requirements for butt weld tests (wire-flux combinations)* as appropriate. The position of fracture of the transverse tensile test is to be reported. The Charpy V-notch impact test requirements are as for the two-run technique in *Table 11.4.3 Requirements for butt weld tests (wire-flux combinations)*.

6.2.7 The results of all longitudinal tensile tests are to comply with the requirements of *Table 11.4.2 Requirements for deposited metal tests (wire-flux combinations)*.

6.2.8 The bend test specimens are to be in accordance with *Ch 11, 4.6 Butt weld test assemblies (two-run technique) 4.6.7* and *Table 11.4.3 Requirements for butt weld tests (wire-flux combinations)*. Each surface of the weld is to be tested in tension.



(1) In the centre of the weld metal



(2) In the weld metal, 2 mm from the fusion line

Figure 11.6.2 Position of Charpy V-notch impact test specimens

6.3 Annual tests

6.3.1 Annual tests are to consist of at least one butt weld test assembly using plate material 20 to 25 mm in thickness.

6.3.2 The assembly is to be prepared and tested in accordance with *Ch 11, 6.2 Butt weld test assemblies* except that only the following tests are required:

(a) One longitudinal tensile test.
(b) One transverse tensile test.
(c) Two bend tests.
(d) Two sets of three Charpy V-notch impact tests; one set with the notch at the centre of the weld (*Figure 11.6.2 Position of Charpy V-notch impact test specimens*), and one set with the notch in the weld metal 2 mm from the fusion line (*Figure 11.6.2 Position of Charpy V-notch impact test specimens*).
(e) Chemical analysis.
(f) One macro-section.

6.3.3 Where a consumable or combination is approved for a range of steels with different specified minimum strength levels, steel of the highest strength level is to be used for the preparation for the assembly required by *Ch 11, 6.3 Annual tests 6.3.1*.

Section 7
Consumables for use in one-side welding with temporary backing materials

7.1 General

7.1.1 The requirements for approval of combinations including temporary backing material, for use in one-side welding techniques, are dependent on the technique used and which basic technique it most closely follows. The following are provided for:

(a) Technique m — for manual electrode/backing combinations.
(b) Technique S — for wire-gas/backing combinations used with semi-automatic multi-run technique.
(c) Technique M — for wire-flux or wire-gas in combination with backing material (and maybe supplementary filler materials) used with an automatic multi-run technique.
(d) Technique A — as for M but using a procedure with a high heat input rate (large bead size relative to thickness welded). This would apply to welds made by four or less runs in 20 mm thickness, or eight or less runs in 35 mm.

7.1.2 For technique m, S or M, a single butt weld is to be made in plate of 20–25 mm thickness. For technique A, two butt welds are to be made, one in plate of the maximum thickness recommended by the manufacturer, the other in plate of approximately half the thickness of the first. Usually this will involve thicknesses in the region of 35–40 mm and 20–25 mm respectively.

7.1.3 A wire and gas combination approved with an argon/carbon dioxide shielding gas where the carbon dioxide content is between 15-25 per cent is also approved for other combinations of argon/carbon dioxide, provided the carbon dioxide content is within the range 15-25 per cent. The range of approval is limited to ferritic consumables in solid wire, flux cored and coated wire forms and subject to the agreement of the consumable manufacturer and LR.

7.1.4 Any unrecognised techniques or unusual combinations will be considered for approval subject to a test programme to be agreed based on the details of the technique and combination which are to be submitted in advance.

7.1.5 Where low hydrogen approval is required either by *Table 11.7.1 Minimum low hydrogen approval requirements for one-side welding with combinations including temporary backing material* or by the manufacturer, it should be noted that this will generally be achieved through separate testing of:

(a) the backing material, and
(b) the welding electrode or combination of wire-flux or wire-gas.

7.1.6 The hydrogen potential of the backing material is to be determined using the modified Gayley-Wooding method which expresses the total hydrogen content as water by weight per cent. The qualifying levels are:

To qualify as:	H_2O g/100g sample
H15	0,5
H10	0,3
H5	0,2

7.1.7 The sampling and approval of the combinations without the backing are to follow the general requirements of *Ch 11, 3 Electrodes for manual and gravity welding*, *Ch 11, 4 Wire-flux combinations for submerged-arc automatic welding* or *Ch 11, 5 Wires and wire-gas combinations for manual, semi-automatic and automatic welding*, as appropriate.

Table 11.7.1 Minimum low hydrogen approval requirements for one-side welding with combinations including temporary backing material

Approval grades	'H' grade for m and S techniques	'H' grade for M technique	'H' grade for A technique
1 (1N), 2 (2N), 3 (3N)	NR	NR	NR
1Y, 2Y, 3Y, 4Y	H15 (*see* Note 2)	NR	NR
2Y40 to 5Y40	H15	H15	NR

3Y47	H10	H10	H15
3Y42 to 5Y42	H10	H10	H15
3Y46 to 5Y46	H10	H10	H15
3Y50 to 5Y50	H10	H10	H10
3Y55 to 5Y55	H5	H5	H10
3Y62 to 5Y62	H5	H5	H5
3Y69 to 5Y69	H5	H5	H5
$1\frac{1}{2}$ Ni	H15	H15	NR
$3\frac{1}{2}$ Ni	H15	H15	NR
5 Ni (*see* Note 3)	NR	NR	NR
9 Ni (*see* Note 3)	NR	NR	NR
Note 1. NR – Not required. Approval may be obtained when requested. Note 2. Optional in this case. If low hydrogen approval is not obtained, there is a limitation on the carbon equivalent of the steel which is permitted to be welded. Note 3. Assumes the use of an austenitic, non-transformable, filler material.			

7.1.8 Combinations approved with multi-run technique (m, S and M) for normal and higher strength levels up to and including 'Y' are also considered suitable for welding steels in the three strength levels below that for which they have been approved.

7.1.9 Combinations approved with multi-run technique (m, S and M) for strength levels Y40 to Y50, but excluding Y47, are also considered suitable for welding steels in two strength levels below that for which they have been approved.

7.1.10 Combinations approved with multi-run technique (m, S and M) for strength levels Y47, Y55 and above are also considered suitable for welding steels in only one strength level below that for which they have been approved.

7.1.11 Combinations approved for the 'A' multi-run technique are not considered suitable for welding steels of any other strength level with that technique.

7.2 Approval tests for manual (m), semi-automatic (S) and automatic multi-run (M) techniques

7.2.1 For each position to be approved, one butt weld assembly is to be prepared using plates of 20 — 25 mm thickness as shown in *Figure 11.7.1 Butt weld test assembly and specimens for all techniques*. The grade of plate used is to be no higher in toughness than that for which approval is required. The strength is to be appropriate to the grade for which welding approval is requested.

7.2.2 The thickness of test assembly is to be 50 mm for Y47 base material.

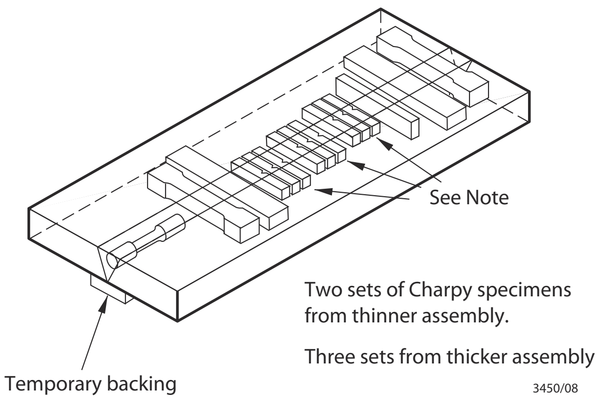


Figure 11.7.1 Butt weld test assembly and specimens for all techniques

Note *see Ch 11, 7.2 Approval tests for manual (m), semi-automatic (S) and automatic multi-run (M) techniques 7.2.4*

7.2.3 The edge preparation and welding conditions are to be in accordance with the recommendations of the manufacturers.

7.2.4 Test specimens are to be prepared as shown in *Figure 11.7.1 Butt weld test assembly and specimens for all techniques* and *Figure 11.7.2 Position of Charpy V-notch impact tests for one-side automatic welding*:

(a) One longitudinal tensile test specimen (from the centre of the weld).
(b) Two transverse tensile specimens.
(c) Two bend test specimens, one with the face in tension, the other with the root in tension.
(d) One macrosection.
(e) Two sets of three Charpy impact test specimens positioned and notched in accordance with *Figure 11.7.2 Position of Charpy V-notch impact tests for one-side automatic welding*.

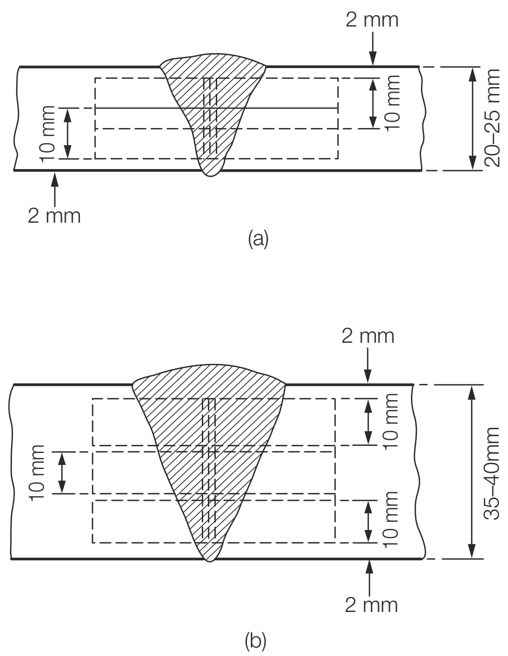


Figure 11.7.2 Position of Charpy V-notch impact tests for one-side automatic welding

7.2.5 The results of all transverse tensile, bend and impact tests are to comply with the requirements in *Table 11.3.3 Requirements for butt weld tests (covered electrodes)* for m and S technique, and *Table 11.4.3 Requirements for butt weld tests (wire-flux combinations)* for M technique. The position of fracture of the transverse tensile test is to be reported. The appearance of the bend test specimens is to be in accordance with *Ch 11, 3.3 Butt weld test assemblies 3.3.13*.

7.2.6 The results of all longitudinal tensile tests are to comply with the requirements in *Table 11.3.2 Requirements for deposited metal tests (covered electrodes)*.

7.2.7 Low hydrogen approval is required in accordance with *Table 11.7.1 Minimum low hydrogen approval requirements for one-side welding with combinations including temporary backing material*.

7.2.8 Chemical analyses are to be made and reported from positions corresponding to the weld metal in the upper and lower Charpy specimens of the downhand butt weld. These are to be supplied by the manufacturer and are to include the content of all significant elements. The results of the analysis are not to exceed the limit values specified in the standards or by the manufacturer, the narrower tolerances being applicable in each case.

7.3 Approval tests for high heat input automatic (A) techniques

7.3.1 Two butt weld assemblies are to be prepared, usually one of 35–40 mm thickness, the other 20–25 mm, as shown in *Figure 11.7.1 Butt weld test assembly and specimens for all techniques*, noting that in the thinner assembly only two sets of Charpy specimens are required. The grade of plates used is to be no higher in toughness than that for which approval is required. The strength is to be appropriate to the grade for which welding approval is requested.

7.3.2 For Y47 grade, the thicker assembly is to be prepared from the maximum thickness for which approval is required, and the thinner assembly is to be prepared from 50 mm thickness. Where approval is required for 50 mm thickness, only one assembly from that thickness is required.

7.3.3 The edge preparation and welding conditions are to be in accordance with the manufacturer's recommendations, and are to be reported to LR.

7.3.4 Test specimens as follows are to be prepared as shown in *Figure 11.7.1 Butt weld test assembly and specimens for all techniques* and *Figure 11.7.2 Position of Charpy V-notch impact tests for one-side automatic welding*:

(a) One longitudinal tensile test specimen (from centre of weld).
(b) Two transverse tensile test specimens.
(c) Two bend test specimens.
(d) One macro-section.
(e) From assembly 20 to 25 mm thick, two sets of three impact test specimens positioned and notched in accordance with *Figure 11.7.2 Position of Charpy V-notch impact tests for one-side automatic welding*.
(f) From assembly 35 to 40 mm thick, three sets of three impact test specimens positioned and notched in accordance with *Figure 11.7.2 Position of Charpy V-notch impact tests for one-side automatic welding*.
(g) From assembly of thickness 50 mm or more, three sets of three impact test specimens positioned and notched in accordance with *Figure 11.7.2 Position of Charpy V-notch impact tests for one-side automatic welding*. The second set positioned in the mid-thickness of test assembly.

The bend specimens are to be tested, one with the face in tension, the other with the root in tension.

7.3.5 The results of all transverse tensile, bend and impact tests are to comply with the requirements of *Table 11.4.3 Requirements for butt weld tests (wire-flux combinations)*. The appearance of the bend test specimens is to be in accordance with *Ch 11, 3.3 Butt weld test assemblies 3.3.13*. The Charpy V-notch impact test requirements are as for the two-run technique in *Table 11.4.3 Requirements for butt weld tests (wire-flux combinations)*.

7.3.6 The results of all longitudinal tensile tests are to comply with the requirements in *Table 11.3.2 Requirements for deposited metal tests (covered electrodes)*, except that for Grades 1Y, 2Y and 3Y the tensile strength is to be not less than 490 N/mm^2.

7.3.7 Low hydrogen approval is required in accordance with *Table 11.7.1 Minimum low hydrogen approval requirements for one-side welding with combinations including temporary backing material*.

7.3.8 Chemical analyses are to be made and reported from positions corresponding to the weld metal in the uppermost and lowest Charpy specimens in the thicker plate weld. This is to be supplied by the manufacturer and is to include the content of all significant elements. The results of the analysis are not to exceed the limit values specified in the standards or by the manufacturer, the narrower tolerances being applicable in each case.

7.4 Annual tests

7.4.1 Annual tests are to consist of, at least, one butt weld test assembly, for each technique approved, using plates of 20 to 25 mm thickness.

7.4.2 The assembly is to be prepared and tested in accordance with *Ch 11, 7.2 Approval tests for manual (m), semi-automatic (S) and automatic multi-run (M) techniques* or *Ch 11, 7.3 Approval tests for high heat input automatic (A) techniques* , as appropriate, except that only the following tests are required:

(a) One longitudinal tensile test (from centre of weld).
(b) One transverse tensile test.
(c) Two bend tests.
(d) One set of three impact tests taken from the root of the weld and the specimens notched in accordance with *Figure 11.7.2 Position of Charpy V-notch impact tests for one-side automatic welding*.
(e) Chemical analysis (one only).

■ *Section 8*
Consumables for welding austenitic and duplex stainless steels

8.1 General

8.1.1 Tests for the approval of consumables intended for welding the austenitic and duplex stainless steels detailed in *Ch 3, 7 Austenitic and duplex stainless steels* are to be carried out generally in accordance with the *Ch 11, 3 Electrodes for manual and gravity welding*, *Ch 11, 4 Wire-flux combinations for submerged-arc automatic welding*, *Ch 11, 5 Wires and wire-gas combinations for manual, semi-automatic and automatic welding*, *Ch 11, 6 Consumables for use in electro-slag and electro-gas welding* or *Ch 11, 7 Consumables for use in one-side welding with temporary backing materials* relevant to the type of consumable or combination.

8.1.2 Approval will be indicated by the grade or grades of parent stainless steel for which the consumable or combination is approved.

8.1.3 Where a shielding gas is employed separate approval will be required for each specific shielding gas composition.

8.1.4 Consumables for welding the austenitic stainless steels and the duplex stainless steels to carbon or carbon-manganese steels will be approved in a similar manner. Parent plate used for the butt and fillet weld test assemblies will be carbon or carbon-manganese steel with either austenitic stainless steel or duplex stainless steel, as appropriate. Approval will be indicated by `SS/CMn' and `Dup/CMn' respectively, however, no buttering of test assembly plates is allowed for these two approvals.

8.1.5 Separate approval will be given for welding chemical and cryogenic applications. For chemical use, evidence of relevant corrosion resistance will be required. Charpy impact toughness tests will be required for all uses, but for cryogenic use the Charpy impact toughness requirements are more severe.

8.1.6 The welding technique will be indicated in the approval grading by a letter:

m = for manual SMAW or GTAW welding.

S = for wire-gas combinations used with a semi-automatic multi-run technique.

M = for wire-flux or wire-gas combinations used with an automatic multi-run technique.

T = for wire-flux or wire-gas combinations used with an automatic two-run technique.

A = as for M but using a procedure with a high heat input rate (large bead size relative to thickness welded). This would apply to welds made by four or less runs in 20 mm thickness, or eight or less runs in 35 mm.

8.2 Deposited metal test assemblies

8.2.1 Where the relevant Section requires deposited metal assemblies to be made and tested, the plates used must be either of the type for which approval is required or of normal strength carbon, or carbon-manganese steel with the prepared edges built up with stainless steel weld metal and finished with a layer of weld metal from the consumable to be approved.

8.2.2 The chemical analysis of the deposited weld metal is to be reported, including all significant elements. The elements reported will be dependent on the type of stainless steel for which approval of the consumables is requested. Any unusual weld metal compositions will have to be justified in respect of the particular approval requested. This is to be supplied by the manufacturer and is to include the content of all significant elements. The results of the analysis are not to exceed the limit values specified in the standards or by the manufacturer, the narrower tolerances being applicable in each case.

8.2.3 The results of all tensile and notch impact tests are to comply with the requirements given in *Table 11.8.1 Requirements for deposited metal tests (manual, semi-automatic and automatic multi-run techniques)* as appropriate.

8.2.4 The ferrite content in the last weld run from each deposited metal assembly is to be determined by physical or metallographic means, and reported, indicating the method of determination.

8.3 Butt weld test assemblies

8.3.1 Where the relevant Section requires butt weld assemblies to be made and tested, the plates used are to be either of the type for which approval is required or of steel having strength and ductility within the range specified for the grade to be approved. In the latter case, provided the consumable is metallurgically compatible with the base material to be used, the prepared edges are to be built up with a layer of weld metal before final machining of the weld preparation.

8.3.2 The results of transverse tensile, notch impact and bend tests are to comply with the requirements of *Table 11.8.2 Requirements for butt weld tests (all techniques)* as appropriate. The position of fracture is to be reported to LR.

8.3.3 The ferrite content at the centre of the weld metal in each butt weld assembly is to be determined by physical or metallographic means, and meet the requirements in *Table 11.8.2 Requirements for butt weld tests (all techniques)*. The method of determination is to be reported.

8.3.4 For austenitic and duplex stainless steel approvals (except for types 304L, 316L, 321, 347, SS/CMn and Dup/CMn), an appropriate sample from each butt weld assembly is to be submitted to the corrosion testing provided in ASTM G48, Method `C'. The results are to be reported so as to allow confirmation of the maximum acceptable pitting corrosion resistance temperature. This will be part of the approval grading and will be set at 5°C intervals. The minimum pitting corrosion temperature would not be expected to be less than 20°C.

8.4 Fillet weld test assemblies

8.4.1 Where the relevant Section requires fillet weld assemblies to be made and tested, the plates used must be either of the type for which approval is required or of steel having strength and ductility within the range specified for the grade to be approved. In the latter case, the surfaces on which the fillet weld beads are to be deposited are to be cut back by machining and then built up to original dimensions with weld metal from the consumable to be approved.

Table 11.8.1 Requirements for deposited metal tests (manual, semi-automatic and automatic multi-run techniques)

Grade	0,2% proof stress N/mm^2 minimum	1% proof stress N/mm^2 minimum	Tensile strength N/mm^2 minimum	Elongation on 50 mm % minimum	Charpy V-notch impact tests		
					Chemical test temperature °C	Cryogenic test temperature °C	Average energy *See* Note 1 J minimum
304L	270	310	500	25	-20	-196	29
304LN	305	345	530	22	-20	-196	29
316L	270	310	500	22	-20	-196	29
316LN	305	345	530	22	-20	-196	29
317L	305	345	530	22	-20	-196	29
317LN	340	380	570	22	-20	-196	29
321	290	330	550	22	-20	-196	29
347	290	330	550	22	-20	-196	29
S 31254	370	410	650	22	-20	-196	29
N 08904	270	310	500	22	-20	-196	29

SS/CMn	270	310	500	22	-20	-60	29
S 31260	485	525	690	20	-20	*see* Note 2	40
S 31803	450	490	620	25	-20	*see* Note 2	40
S 32550	550	590	760	15	-20	*see* Note 2	40
S 32750	550	590	800	15	-20	*see* Note 2	40
S 32760	550	590	750	25	-20	*see* Note 2	40
Dup/CMn	270	310	500	22	-20	*see* Note 2	40

Note 1. Energy values from individual impact test specimens are to comply with *Ch 11, 1.4 Approval procedures 1.4.3*.

Note 2. Approval for cryogenic applications is to be obtained at the procedure approval stage.

Table 11.8.2 Requirements for butt weld tests (all techniques)

Grade	Tensile strength N/mm^2 minimum	Bend test ratio: $\frac{D}{t}$	Weld ferrite content %	Charpy V-notch impact tests		
				Chemical test temperature °C	Cryogenic test temperature °C	Average energy (*see* Note 1) J minimum
304L	500	3	4-12	-20	-196	27
304LN	530	3	4-12	-20	-196	27
316L	500	3	4-12	-20	-196	27
316LN	530	3	4-12	-20	-196	27
317L	530	3	4-12	-20	-196	27
317LN	570	3	4-12	-20	-196	27
321	550	3	4-12	-20	-196	27
347	550	3	4-12	-20	-196	27
S 31254	650	3	(*see* Note 2)	-20	-196	27
N 08904	500	3	(*see* Note 2)	-20	-196	27
SS/CMn	500	3	4-12	-20	-60	27
S 31260	690	4	35-65	-20	(*see* Note 3)	40
S 31803	620	3	35-65	-20	(*see* Note 3)	40
S 32550	760	6	35-65	-20	(*see* Note 3)	40
S 32750	800	6	35-65	-20	(*see* Note 3)	40
S 32760	750	6	35-65	-20	(*see* Note 3)	40
Dup/CMn	500	3	(*see* Note 2)	-20	(*see* Note 3)	40

Note 1. Energy values from individual impact test specimens are to comply with *Ch 11, 1.4 Approval procedures 1.4.3*.

Note 2. To be reported for special consideration.

Note 3. Approval for cryogenic applications is to be obtained at the procedure approval stage.

8.4.2 The ferrite content at the centre of the weld metal in each fillet weld bead of each assembly is to be determined from the centre macro-section by physical or metallographic means, and reported. The method of determination is also to be reported to LR.

8.4.3 Where approval is sought for fillet welding only, corrosion testing is to be carried out in accordance with *Ch 11, 8.3 Butt weld test assemblies 8.3.4* from a sample taken from the deposited metal test assembly.

8.5 Annual tests

8.5.1 Annual tests are to be carried out as required by the relevant Section appropriate to the type of consumable and welding technique. The tests are to include a weld ferrite content in accordance with *Ch 11, 8.2 Deposited metal test assemblies 8.2.4* or *Ch 11, 8.3 Butt weld test assemblies 8.3.3* as appropriate.

8.5.2 The results of all tests are to comply with the requirements given in *Table 11.8.1 Requirements for deposited metal tests (manual, semi-automatic and automatic multi-run techniques)* and *Table 11.8.2 Requirements for butt weld tests (all techniques)* as appropriate.

■ *Section 9*
Consumables for welding aluminium alloys

9.1 General

9.1.1 Tests for the approval of consumables intended for welding the aluminium alloys detailed in *Ch 8 Aluminium Alloys* are to be carried out generally in accordance with the requirements of *Ch 11, 1 General*, *Ch 11, 2 Mechanical testing procedures* and *Ch 11, 5 Wires and wire-gas combinations for manual, semi-automatic and automatic welding*, except as otherwise detailed in this Section.

9.1.2 Approval will be indicated by the grade shown in *Table 11.9.1 Requirements for butt weld tests*. Plate of the corresponding type of aluminium alloy and of appropriate thickness is to be used for the preparation of the weld test assemblies, and may be of any temper listed in LR Rules.

Table 11.9.1 Requirements for butt weld tests

Consumable Approval Grade (*see* Note 1)	Base material used for the test	Tensile strength N/mm^2 minimum	Bend test ratio $\frac{D}{t}$
LR RA/LR WA	5754	190	3
LR RB/LR WB	5086	240	6
LR RC1/LR WC1	5083	275	6
LR RC2/LR WC2 (*see* Note 2)	5383 or 5456	290	6
LR RC3/LR WC3 (*see* Note 2)	5059	330	6
LR RD/LR WD (*see* Note 4)	6005A	170	6
	6061	170	6
	6082	170	6

Note 1. The prefixes 'R' and 'W' indicate 'rod' form (for Gas Tungsten Arc Welding (GTAW)) or 'wire' form (for Gas Metal Arc Welding (GMAW) and GTAW).

Note 2. Approval of grade LR RC2/LR WC2 confers approval of 5383, 5456 and 5083 base material grade.

Note 3. Approval of grade LR RC3/LR WC3 confers approval of 5059, 5383, 5456 and 5083 base material grades.

Note 4. Approval of grade LR RD/LR WD confers approval of 6005A, 6061 and 6082 base material grades.

9.1.3 The welding technique will be indicated in the approval grading by a letter:

m = manual multi-run welding (GTAW),

S = semi-automatic multi-run welding (GMAW),

M = automatic multi-run welding (GTAW or GMAW),

T = automatic two-run welding (GMAW).

9.1.4 The compositions of the shielding gas and the filler/electrode wire are to be reported.

9.1.5 Approval granted using the multi-run technique for a specific filler/electrode wire with a gas in one of the groups listed in *Table 11.9.2 Shielding gas compositions* will extend to any other gas compositions within that same group, provided that the gas composition is within the range recommended by the consumable manufacturer, subject to agreement with LR.

Table 11.9.2 Shielding gas compositions

Group	Gas composition (Vol. %) (see Note)	
	Helium	Argon
I-1	—	100
I-2	100	—
I-3	>0 ≤33	Remainder
I-4	>33 ≤66	Remainder
I-5	>66 ≤95	Remainder
S	Special gas	

Note Gases of other composition (mixed gases) or special purity may be considered as special gases and will require separate approval tests.

9.1.6 Approval granted for the two-run technique will be for a specific shielding gas composition; additional tests may be required if a change in shielding gas composition is sought.

9.1.7 On completion of welding, assemblies are to be allowed to cool naturally to ambient temperature. Welded test assemblies and test specimens are not to be subjected to any heat treatment after welding except for the alloy Grades 6005A, 6061 and 6082. These are to be allowed to naturally age at ambient temperature for a period of 72 hours from the completion of welding, before testing is carried out. A second solution heat treatment is not permitted.

9.1.8 All butt test assemblies are to be subjected to both radiographic and visual examination and imperfections such as lack of fusion, lack of penetration, cavities, inclusions, pores and cracks assessed in accordance with Intermediate Level C of ISO 10042, aided where necessary by dye penetrant and ultrasonic examination.

9.1.9 Fillet weld test assemblies and macro-sections are to be visually examined for imperfections, such as lack of fusion, lack of penetration, cavities, inclusions, pores and cracks, in accordance with Intermediate Level C of ISO 10042, aided where necessary by radiographic and dye penetrant examination.

9.2 Approval tests for manual, semi-automatic and automatic multi-run techniques

9.2.1 Plate of the corresponding type of aluminium alloy and of appropriate thickness is to be used for the preparation of the weld test assemblies.

9.2.2 The welding parameters are to be within the range recommended by the manufacturer and are to be reported.

9.2.3 Welded assemblies are to be prepared and tested in accordance with *Ch 11, 9.3 Deposited metal test assembly*, *Ch 11, 9.4 Butt weld test assemblies* and *Ch 11, 9.5 Fillet weld test assembly*.

9.3 Deposited metal test assembly

9.3.1 One assembly is to be prepared in the downhand position as shown in *Figure 11.9.1 Deposited metal test assembly*.

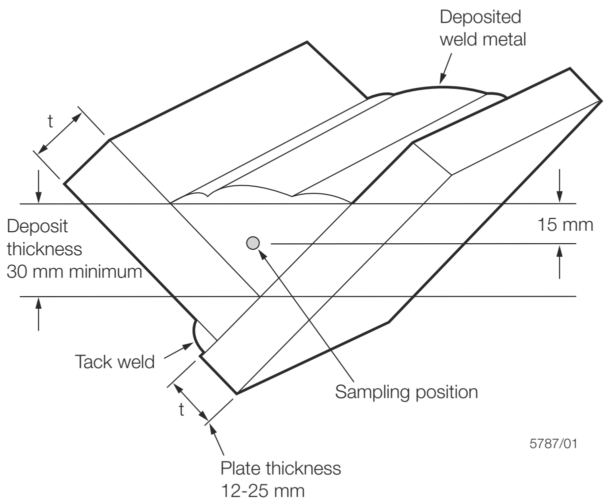


Figure 11.9.1 Deposited metal test assembly

9.3.2 The chemical composition of the plate used for the assembly is to be compatible with the weld metal.

9.3.3 The thickness of the plate used, and the length of the assembly, are to be appropriate to the welding process. The plate thickness is to be not less than 12 mm.

9.3.4 For the approval of filler wire/gas and electrode wire/gas combinations for manual or semi-automatic welding by GTAW or GMAW, one test assembly is to be welded using any size of wire within the range for which approval is sought.

9.3.5 For automatic multi-run approval, one test assembly is to be welded by the respective process using the recommended diameter of wire.

9.3.6 The weld metal is to be deposited in multi-run layers in accordance with normal practice. The direction of deposition of each layer is to alternate from each end of the plate.

9.3.7 The deposited weld metal in the assembly is to be analysed and reported including the contents of all significant elements. The elements reported will be dependent on the type of aluminium alloy for which approval of the consumables is requested. The results of the analysis are not to exceed the limit values specified in the standards or by the manufacturer, the narrower tolerances being applicable in each case.

9.4 Butt weld test assemblies

9.4.1 Plate of the corresponding type of aluminium alloy and of an appropriate thickness is to be used for the preparation of the test assemblies.

9.4.2 In order to ensure sound and representative welds, it is essential that test assemblies are cleaned and degreased prior to welding. Assemblies as shown in *Figure 11.9.2 Butt weld test assembly (positional, multi-run technique)* are to be prepared for each welding position (downhand, horizontal-vertical, vertical-upward, vertical-downward, and overhead) for which the consumable is recommended by the manufacturer; except that consumables satisfying the requirements for downhand and vertical-upward positions will be considered as also complying with the requirements for the horizontal-vertical position. Any wire diameter(s) to be approved may be used.

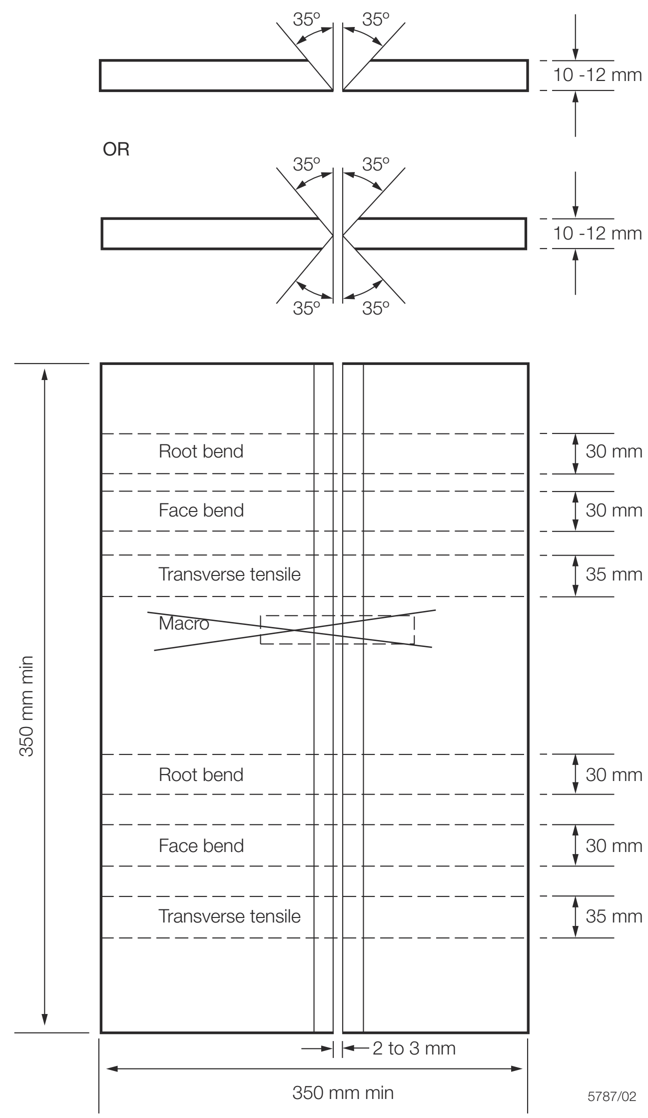


Figure 11.9.2 Butt weld test assembly (positional, multi-run technique)

9.4.3 One assembly, as shown in *Figure 11.9.3 Butt weld test assembly (downhand, multi-run technique)*, is to be prepared for welding in the downhand position. The assembly is to be welded using, for the first run, wire of the smallest diameter recommended by the manufacturer and, for the remaining runs, wire of the largest diameter to be approved.

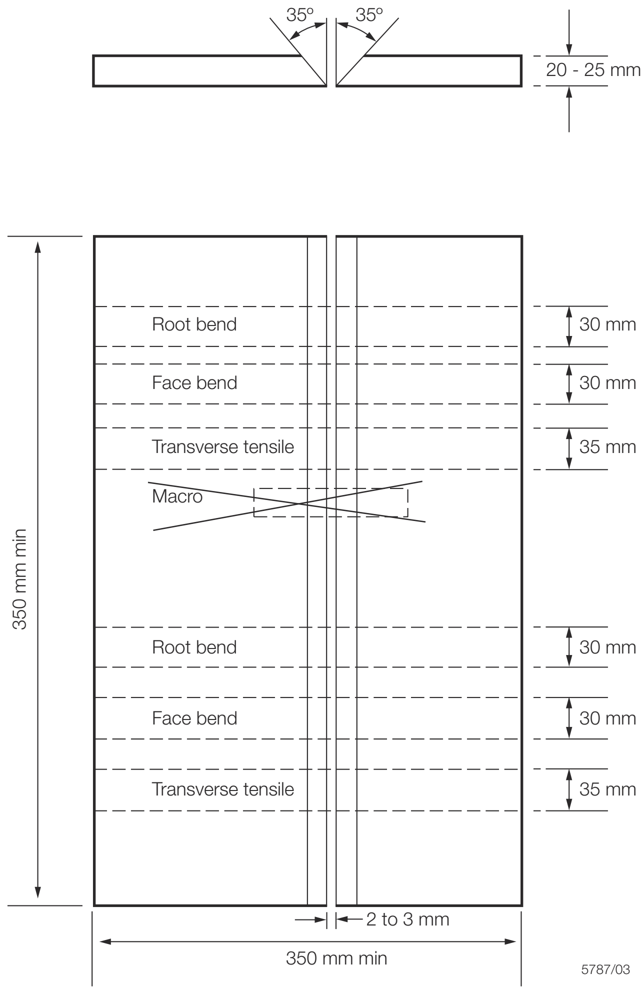


Figure 11.9.3 Butt weld test assembly (downhand, multi-run technique)

9.4.4 The welding conditions are to be in accordance with the recommendations of the manufacturer and are to be reported in detail.

9.4.5 The welded assemblies are to be subjected to NDE. Imperfections are to be assessed in accordance with *Ch 11, 9.1 General 9.1.8*.

9.4.6 The test specimens are to be taken from the welded assemblies as shown in *Figure 11.9.2 Butt weld test assembly (positional, multi-run technique)* and *Figure 11.9.3 Butt weld test assembly (downhand, multi-run technique)*. For each assembly they are to comprise:

- 2 transverse tensile specimens;
- 2 face bend specimens; and
- 2 root bend specimens.

9.4.7 All tensile test specimens are to have a tensile strength not less than the respective value shown in *Table 11.9.1 Requirements for butt weld tests*. The position of each fracture is to be reported.

9.4.8 The bend test specimens are to be bent around a former having a diameter not more than the number of times the thickness of the test specimen, as shown in *Table 11.9.1 Requirements for butt weld tests*, and can be considered as complying with the requirements if, after bending to an angle of not less than 180°, no crack or other open defect exceeding 3 mm in length can be seen on the outer surface. Flaws appearing at the corners of a test specimen may be ignored.

9.4.9 In order to obtain uniform bending of the bend test specimens, it is recommended that the wrap-around or guided bend test using a roller method is employed.

9.5 Fillet weld test assembly

9.5.1 When approval is being sought for both butt and fillet welding, one assembly is to be prepared and welded in the horizontal-vertical position and tested in accordance with the appropriate requirements of *Ch 11, 3.5 Fillet weld test assemblies*, except that the plates are to be of an aluminium alloy compatible with the weld metal, that no hardness tests are required and that for automatic multi-run approval only one fillet weld bead is to be made using the recommended wire diameter. In this case, the bead size is to be as large as the maximum single bead size recommended by the manufacturer for fillet welding.

9.5.2 When approval is being sought for fillet welding only, one assembly is to be prepared and welded in each position for which approval is sought, and tested as detailed in *Ch 11, 9.5 Fillet weld test assembly 9.5.1*.

9.5.3 The results of examination of the macro-specimens and the fractured fillet welds are to be reported in accordance with *Ch 11, 3.5 Fillet weld test assemblies 3.5.4* and *Ch 11, 3.5 Fillet weld test assemblies 3.5.6*. Imperfections are to be assessed in accordance with *Ch 11, 9.1 General 9.1.9*.

9.6 Approval tests for two-run technique

9.6.1 Two butt weld test assemblies are to be prepared using the following plate thicknesses:

(a) one with the maximum thickness for which approval is requested,
(b) one with a thickness approximately one half to two thirds that of the maximum thickness.

9.7 Butt weld test assemblies (two-run technique)

9.7.1 The plates used are to be of the aluminium alloy appropriate to the approval required as shown in *Table 11.9.1 Requirements for butt weld tests*. The composition of the plate material is to be within the range specified for that alloy in *Table 8.1.2 Chemical composition, percentage* in *Ch 8 Aluminium Alloys* and is to be reported including all significant elements.

9.7.2 The wire diameter, edge preparation, welding current, arc voltage and travel speed are to be in accordance with the manufacturer's recommendations and are to be reported.

9.7.3 Each butt weld is to be made in two runs, one from each side. After completion of the first run the assembly is to be left in still air until it has cooled to less than 50°C.

9.7.4 The welded assemblies are to be subjected to NDE. Imperfections are to be assessed in accordance with *Ch 11, 9.1 General 9.1.8*.

9.7.5 The test specimens as shown in *Figure 11.9.4 Butt weld test assembly (two-run technique)* are to be prepared from each test assembly. The edges of the discards are to be polished and etched, and must show complete fusion and inter-run penetration of the welds. Each cut in the assembly is also to be examined to confirm that complete fusion and penetration have been achieved.

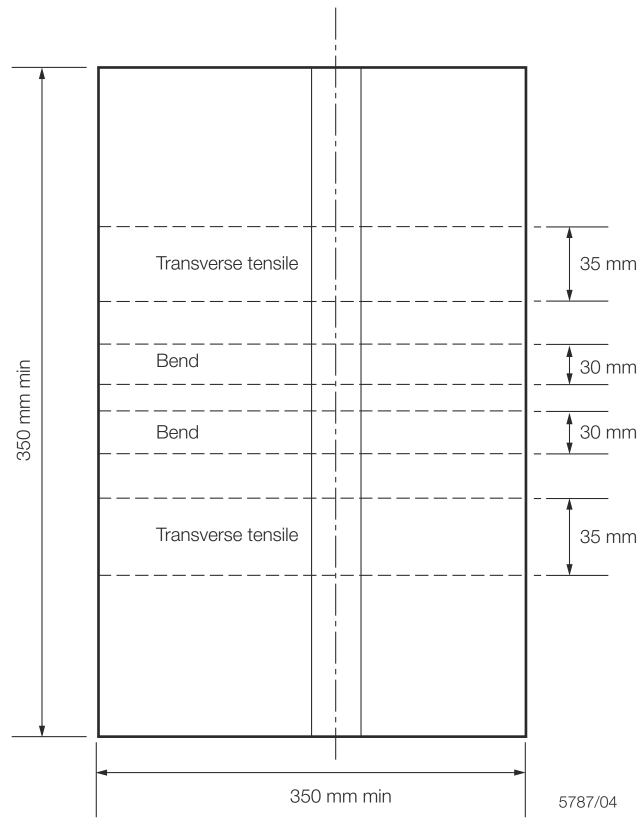


Figure 11.9.4 Butt weld test assembly (two-run technique)

9.7.6 The results of the transverse tensile tests are to be as in *Ch 11, 9.4 Butt weld test assemblies 9.4.7* and of the bend tests as in *Ch 11, 9.4 Butt weld test assemblies 9.4.8*. The position of the fracture in each transverse tensile specimen is to be reported.

9.8 Annual tests

9.8.1 Annual tests are to consist of the following:

(a) for combinations approved for the multi-run technique, one deposited metal assembly in accordance with *Ch 11, 9.3 Deposited metal test assembly* and one downhand butt assembly in accordance with *Ch 11, 9.4 Butt weld test assemblies Figure 11.9.2 Butt weld test assembly (positional, multi-run technique)*;

(b) for combinations approved for the two-run technique, one butt weld assembly in accordance with *Ch 11, 9.7 Butt weld test assemblies (two-run technique)* using plate material of thickness equal to one half to two thirds that of the maximum thickness approved.

Contents

Welding Qualifications

■ *Section 1*
General qualification requirements

1.1 General

1.1.1 This Section applies to all welding qualifications and tests required to be performed in the course of new construction, conversions, modifications or repairs made on ships, other marine structures and their associated pressure vessels, machinery and equipment.

1.1.2 These Rules also apply to all welding work related to other applications for which Lloyd's Register (hereinafter referred to as LR) have issued Rules or have an interest.

1.1.3 It is the responsibility of the manufacturer to ensure compliance with all aspects of these Rules. All deviations are to be recorded as non-compliances and brought to the attention of the Surveyor along with the corrective actions taken. Failure to do this is considered to render the welding tests as not complying with the Rules.

1.1.4 Welding tests are to be performed under survey at the manufacturer's works. Welding procedure qualification tests and welder qualifications tests are to be performed and approved prior to commencement of fabrication or construction.

1.1.5 Weld procedure tests made in accordance with EN, ISO, JIS, ASME or AWS may be considered for acceptance provided that, as a minimum, they are equivalent to and meet the technical intent of these Rules to the satisfaction of the Surveyor.

1.1.6 Welding tests that have previously been carried out may be considered for acceptance, provided that they have been supervised by an independent body acceptable to LR and the Surveyor is satisfied with the authenticity of such tests.

1.1.7 The responsibility for the performance of the weld tests rests with the manufacturer. Aspects of the welding tests, such as mechanical testing, non-destructive testing and heat treatment, may be subcontracted by the manufacturer provided that the subcontractor performs the work under the technical control and direction of the manufacturer, and this is agreed with the Surveyor prior to commencing the work.

1.1.8 In these Rules, the term 'manufacturer' is considered to include any firm or organisation that performs welding and is considered to be the shipbuilder, or construction firm, or fabricator, or material manufacturer.

1.2 Design

1.2.1 Welding procedure qualification tests are required to give assurance that construction welds made in accordance with the approved plans or the approved design have acceptable properties. It is the manufacturer's responsibility to establish and document whether a procedure is suitable for a particular application.

1.2.2 The requirements relate to mechanical properties of the weld and heat affected zone, however, other tests may be required on certain materials, for example, corrosion or fatigue tests, in order to ensure suitability for the proposed application.

1.3 Materials

1.3.1 Materials used for testing are to be of the same grade, type and from the same manufacturing process as those to be used for construction, unless prior agreement is obtained from the Surveyor. Such agreements will only apply on a case-by-case basis.

1.3.2 All materials used for testing are to be suitably marked and identifiable to the original manufacturer's material certificate.

1.4 Performance of welding tests

1.4.1 All welding and subsequent testing is to be performed in accordance with the requirements of this Chapter.

1.4.2 The manufacturer is responsible for monitoring the tests and for recording all the welding variables as specified in 2.2 and for compiling all the non-destructive examination (NDE) reports and mechanical test records for submission to the Surveyor.

1.4.3 The laboratory or testing establishment used to perform the tests is to have the necessary equipment, maintained in good order and suitably calibrated. The Surveyor is to be satisfied that the laboratory personnel have the appropriate skills and are appropriately qualified in accordance with *Ch 2, 1.2 Testing machines 1.2.1*.

■ *Section 2*
Welding procedure qualification tests for steels

2.1 General

2.1.1 The requirements of this Section relate to welding procedure test requirements of carbon, carbon-manganese steels and low alloys steels. Additional requirements for austenitic and austenitic/ferritic duplex stainless steels, aluminium and copper alloys are specified in Sections 3 and 4 respectively.

2.1.2 Prior to performing the welding procedure qualification test, the manufacturer is to present to the Surveyor a preliminary Welding Procedure Specification (pWPS) detailing the welding processes, positions, joint types, materials and heat treatments to be performed during the test. The pWPS is to be presented for information prior to commencing the test.

2.1.3 The type and extent of testing to be applied to each welding procedure test is to be in accordance with subsequent Sections of this Chapter.

2.1.4 For the welding procedure approval, the welding procedure qualification tests given in this Section are to be carried out with satisfactory results. Welding procedure specifications are to refer to the test results achieved during welding procedure qualification testing.

2.2 Welding variables

2.2.1 In order that the conditions of the qualification test may be applied to production welding operations, the appropriate variables are to be recorded by the manufacturer during welding and testing from the following list:

(a) The unique qualification reference number and the date of welding;
(b) The material type, grade, product form, dimensions and identification;
(c) Welding process(es), including tack welds;
(d) Joint type, dimensions and surface condition;
(e) Welding position(s);
(f) Welding technique(s), weaving, multiple electrodes, etc;
(g) Welding consumables including fluxes, shielding gases, etc;
(h) Control of consumables, baking or drying conditions, etc;
(i) Welding parameters, current, voltages, travel speeds, etc;
(j) Number and sequence of weld runs;
(k) Backing materials including any backing gas;
(l) Preheats and interpass temperatures;
(m) Methods used for cleaning and inspection of root deposits;
(n) Post-weld heat treatment, temperature and cycle times;
(o) Special weld profiling requirements.

2.2.2 Other variables may need to be recorded depending on the particular welding process or application and are to be agreed with the Surveyor, for example the peak and base current and cycle times for pulse welding, electrode type and nozzle size for GTAW welding, etc.

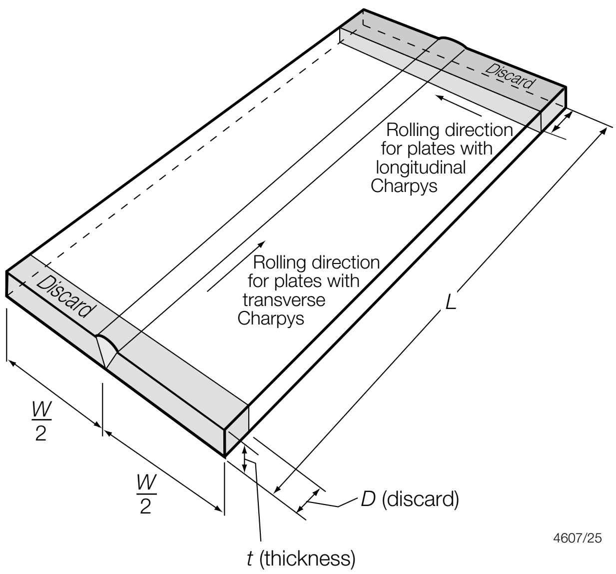
2.3 Steel test assemblies

2.3.1 Tests are to be performed using the welding process and positioGUID-7CEB36FA-B717-46C0-8DC5-C287A4AAB299ns anticipated for actual construction. The weld test assemblies are to be representative of construction

conditions and are to be welded in the same manner as intended for the actual production welds. Where prefabrication primers are used in the shipyard, these are to be included in the test assemblies.

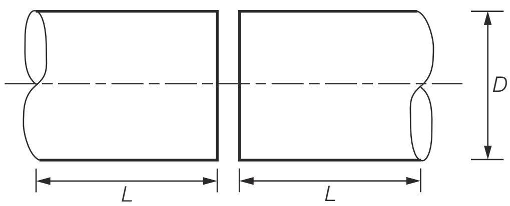
2.3.2 For plate tests, the direction of plate rolling relative to the weld direction is to be considered. Where the material used for the test requires longitudinal impact tests, the plate rolling direction is to be perpendicular to the weld direction and for material which requires impact testing in the transverse direction, the rolling direction is to be parallel to the weld direction. For weld tests intended for liquefied gas storage or cargo tanks and associated process pressure vessels, the direction of plate rolling is to be parallel to the weld direction in all cases.

2.3.3 Typical test assemblies are shown in *Figure 12.2.1 Butt weld test assembly in plate* to *Ch 12, 2.3 Steel test assemblies 2.3.3*. These are a minimum requirement to permit the removal of all the necessary mechanical test specimens. Where impact tests or other toughness tests are required, the total width is not to be less than 8 times the material thickness of the thicker material being joined.



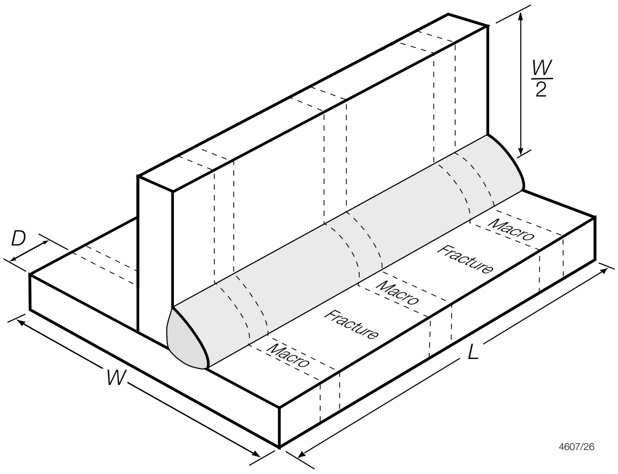
Welding Processes	L (min) mm	W (min) mm	D (min) mm
Manual/Semi-automatic	350	300	50
Automatic	1000	400	75

Figure 12.2.1 Butt weld test assembly in plate



L = 150 mm minimum
D = Outside diameter

Figure 12.2.2 Butt weld test assembly in pipe



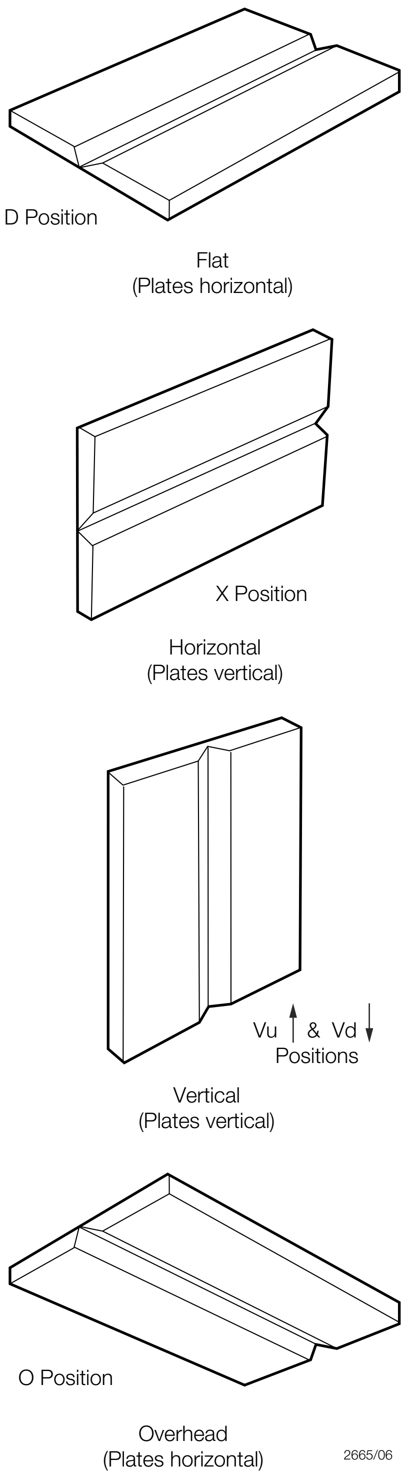
Welding Processes	*L* (min) mm	*W* (min) mm	*D* (min) mm
Manual/Semi-automatic	350	300	50
Automatic	1000	300	75

Figure 12.2.3 Fillet weld test assembly in plate

2.3.4 Welding procedure test assemblies are to be welded separately from production welds and are to be marked with the unique test identification number. The individual pieces of the test assembly may be held together to maintain their relative joint conditions by means of suitable tack welds, clamps or strongbacks.

2.3.5 Welding of the test assemblies and testing of test specimens is to be monitored by the Surveyor.

2.3.6 The test assembly is to be placed in one of the welding positions shown in *Figure 12.2.4 Plate butt weld test positions* to *Ch 12, 2.3 Steel test assemblies 2.3.6*, as specified in the test Welding Procedure Specification (pWPS) and the specified level of preheat applied prior to the start of welding.



Position of test plates for plate assemblies

Figure 12.2.4 Plate butt weld test positions

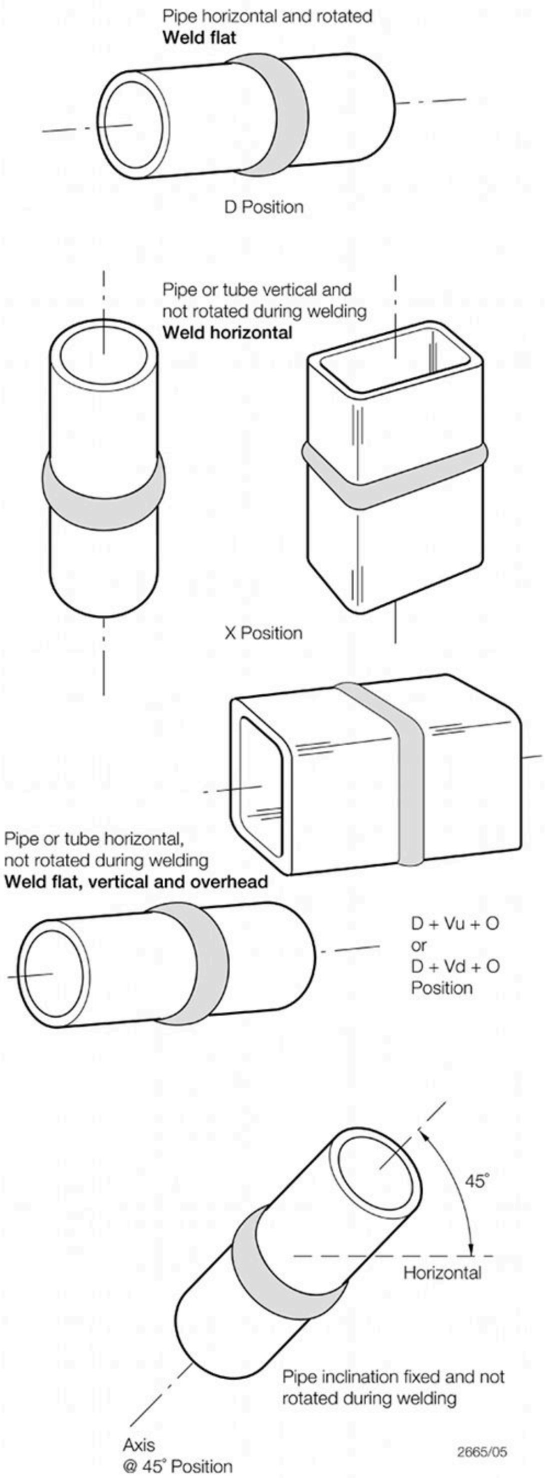


Figure 12.2.5 Pipe butt weld test positions

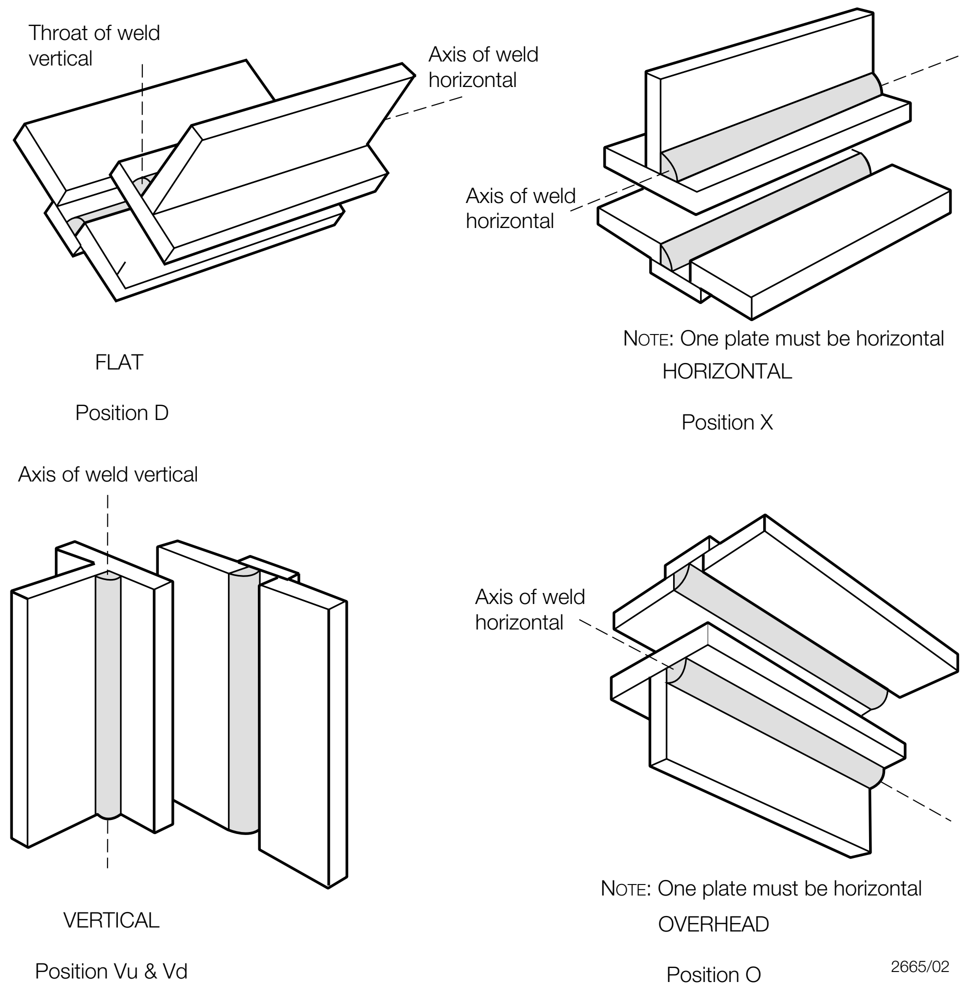


Figure 12.2.6 Plate fillet weld test positions

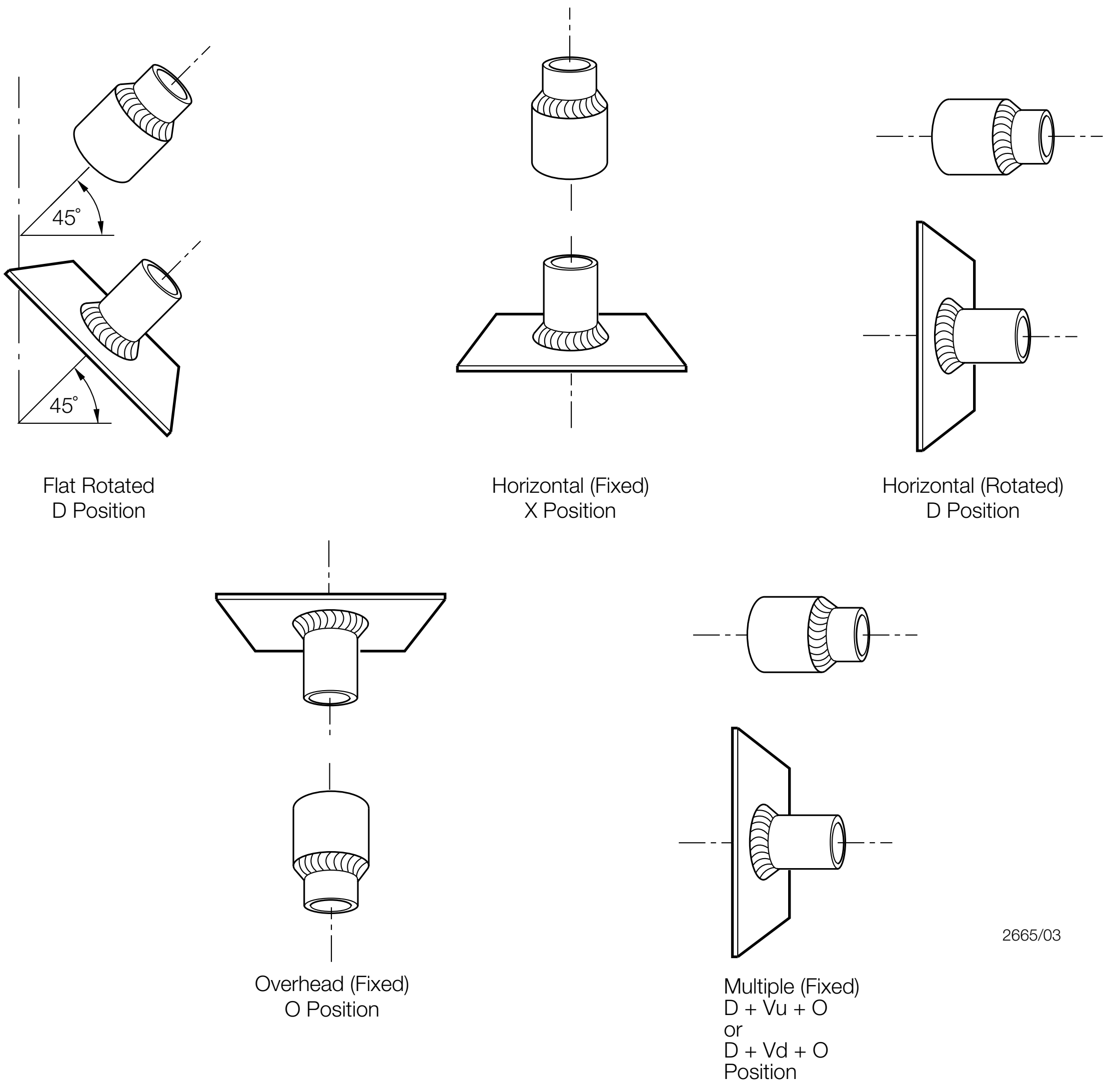


Figure 12.2.7 Pipe fillet weld test positions

2.3.7 Designations for equivalent welding positions shown by different standards are shown in *Table 12.2.1 Equivalent designations of welding positions*.

Table 12.2.1 Equivalent designations of welding positions

Weld position		Standard	
		ISO 6947	AWS
Plate butt welds			
Flat	D	PA	1G
Horizontal	X	PC	2G
Vertical, weld up	Vu	PF	3G
Vertical, weld down	Vd	PG	3G
Overhead	O	PE	4G

Pipe butt welds			
Pipe horizontal, rotated, weld horizontal	D	PA	1G
Pipe vertical, not rotated, weld horizontal	X	PC	2G
Pipe horizontal, not rotated, weld flat, vertical and overhead	D+Vu+O	PH	5G
	D+Vd+O	PJ	
Pipe inclination fixed, not rotated	45º	H-L045	6G
		J-L045	
Plate fillet welds			
Flat	D	PA	1F
Horizontal	X	PB	2F
Vertical up	Vu	PF	3F
Vertical down	Vd	PG	3F
Overhead	O	PD	4F
Pipe fillet welds			
Flat, pipe rotated	D	PA	1FR
Horizontal, pipe fixed	X	PB	2F
Horizontal, pipe rotated	D	PB	2FR
Overhead, pipe fixed	O	PD	4F
Multiple, pipe fixed	D+Vu+O	PF	5F
	D+Vd+O	PG	

2.4 Welding of steel test assemblies

2.4.1 Welding of the test assembly is to be carried out in accordance with the agreed pWPS. Where, during the progress of the test, it is found necessary to change the conditions specified on the pWPS, this is to be brought to the attention of the Surveyor. If agreed, the test may be permitted to continue with the new conditions and these are to be recorded.

2.4.2 Where the production work requires welding over tack welds, the test is to simulate this condition and the tack welds are to be included in the inspection length of the test weld and their position recorded.

2.4.3 For manual and semi-automatic welding processes, weld stops and re-starts are to be included in the inspection length of the test weld.

2.4.4 Fillet weld test assemblies are welded on one side only.

2.4.5 Where the construction welding is predominately fillet welding, in addition to the butt weld qualification test, a fillet weld qualification test is to be performed to confirm that acceptable weld quality is achieved.

2.5 Non-destructive examination (NDE)

2.5.1 On completion of welding, prior to sectioning for mechanical tests, the inspection length of the test assembly is to be subjected to both visual examination and surface crack detection.

2.5.2 Butt weld assemblies are also to be subjected to radiographic or ultrasonic examination over the whole inspection length of the weld.

2.5.3 For welds in steels with specified yield strength up to 400 N/mm^2, and with carbon equivalent less than or equal to 0,41 per cent, NDE may be performed as soon as the test assembly has cooled to ambient temperature. For other steels, NDE is to be delayed for a period of at least 48 hours after the test assembly has cooled to ambient temperature.

2.5.4 Where post-weld heat treatment is required, NDE is to be performed after the heat treatment is complete.

2.5.5 All NDEs are to be carried out in accordance with the requirements of *Ch 1, 5 Non-destructive examination*. Assessment of results is to be in accordance with ISO 5817 Level B except for excess convexity and excess throat thickness where Level C will apply. Linear porosity is not permitted.

2.5.6 As an alternative to radiography, ultrasonic examination may be carried out and acceptance criteria that are considered to result in equivalent weld quality (in accordance with *Ch 12, 2.5 Non-destructive examination (NDE) 2.5.5*) are to be agreed, with the Surveyor, prior to the tests being carried out. Ultrasonic testing will be subject to the thickness limitation specified in *Ch 13, 2.12 Non-destructive examination of welds 2.12.5*.

2.5.7 Where the test assembly does not satisfy the nondestructive examination acceptance criteria, the test is to be rejected. A duplicate test assembly may be welded using the original welding conditions. If this fails NDE, the welding procedure is to be considered as incapable of achieving the requirements without modification.

2.5.8 Subject to prior agreement with the Surveyor, where unacceptable imperfections are of a volumetric nature and are localised in one small area of the test assembly, the test may be permitted to continue and specimens for destructive testing may be removed, avoiding this area.

2.6 Destructive tests – General requirements

2.6.1 The weld test assembly may only be sectioned for destructive testing after any heat treatment and the required non-destructive examinations have been completed successfully.

2.6.2 The dimensions of the test specimens and testing conditions are to be in accordance with the requirements specified in *Ch 2 Testing Procedures for Metallic Materials*.

2.6.3 The results of destructive tests are to be assessed in accordance with the acceptance criteria specified in *Ch 12, 2.12 Mechanical test acceptance criteria for steels*, unless other, more stringent requirements are specified for the application.

2.6.4 Where a weld test is made between materials of different grades, the acceptance criteria that are to be applied are those applicable to the lower grade material.

2.7 Destructive tests for steel butt welds

2.7.1 The test assembly is to be sectioned for mechanical testing in accordance with *Figure 12.2.8 Butt welds in plate and pipe over 750 mm diameter* or *Figure 12.2.9 Butt welds in pipe less than 750 mm diameter*.

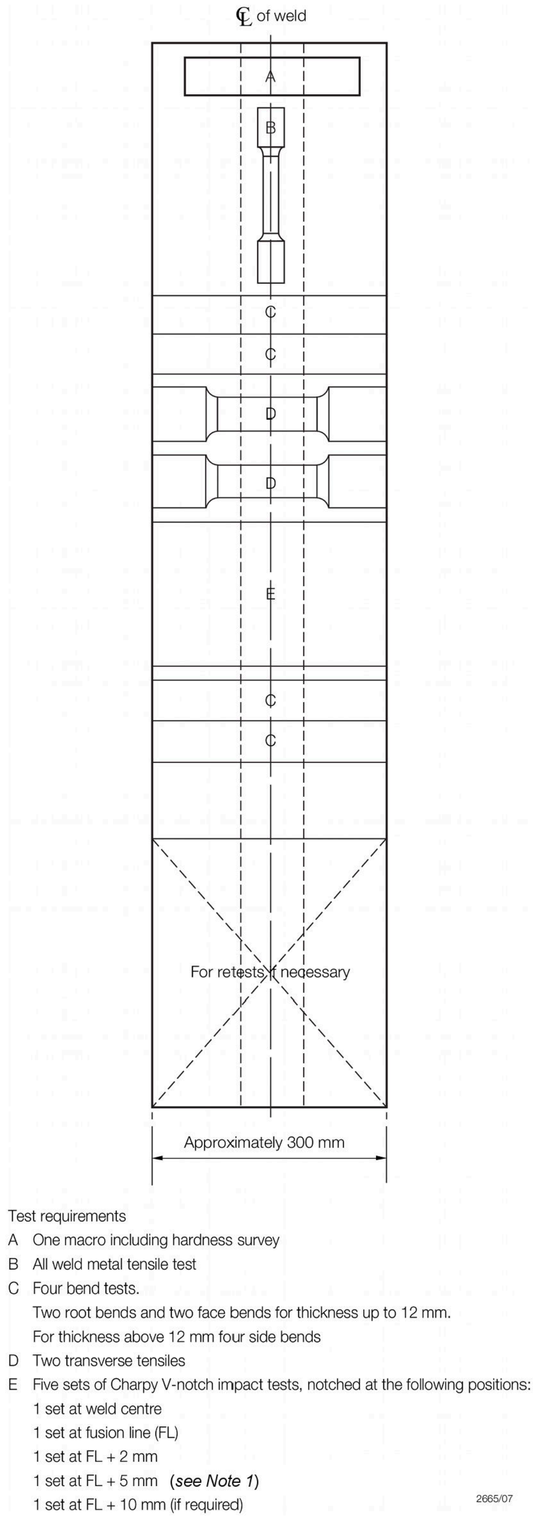
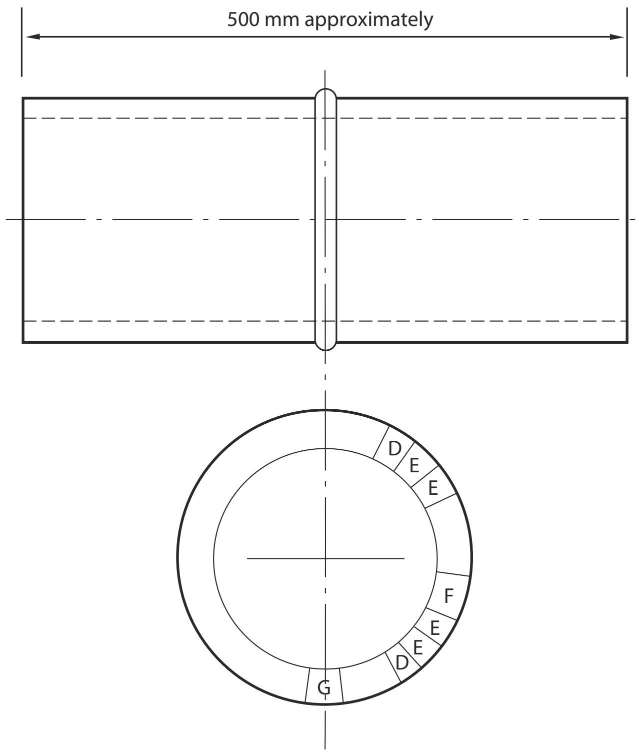


Figure 12.2.8 Butt welds in plate and pipe over 750 mm diameter

Note If required by *Figure 12.2.11 Locations of V-notch for butt weld of normal heat input (heat input ≤ 50 kJ/cm)* and *Figure 12.2.12 Locations of V-notch for butt weld of high heat input (heat input > 50 kJ/cm)*



The diameter of the test piece is to be a minimum of D/2
where
D is the maximum diameter of the pipe to be welded in construction

Test requirements
A Visual examination
B Surface crack detection
C 100% radiographic examination
D Two transverse tensile tests
E Four bend tests.
Four side bends for thickness greater than 12 mm.
In other cases, two face and two root bends
F Four sets Charpy V-notch impact tests
1 set notched at centre of weld
1 set notched at fusion line (FL)
1 set notched at FL + 2 mm
1 set notched at FL + 5 mm (See Note)
G One macro specimen including hardness survey

Figure 12.2.9 Butt welds in pipe less than 750 mm diameter

Note If required by *Figure 12.2.11 Locations of V-notch for butt weld of normal heat input (heat input ≤ 50 kJ/cm)* and *Figure 12.2.12 Locations of V-notch for butt weld of high heat input (heat input > 50 kJ/cm)*

2.7.2 The longitudinal all weld metal tensile test specimen is to be of circular cross-section as detailed in *Ch 11, 2.1 Dimensions of test specimens 2.1.1*. Where more than one welding process or type of consumable has been used to make the weld, test specimens are to be removed from each respective area of the weld. This does not apply to the process or consumables used to make the root or first weld run. During the test, the yield or proof stress, ultimate tensile strength, and elongation to failure are to be recorded.

2.7.3 Where approved welding consumables have been used, the longitudinal all weld metal tensile test may be omitted. For Type C independent tanks intended for liquefied gases, the all weld tensile test is mandatory for all welding procedure tests.

2.7.4 The transverse tensile test specimen is to be of full thickness with the dimensions shown in *Ch 11, 2.1 Dimensions of test specimens 2.1.1*. The tensile strength and fracture locations are to be reported.

2.7.5 Where the maximum load required to fracture the transverse tensile specimen is likely to exceed the capacity of the tensile testing equipment, several tensile specimens may be removed through the thickness and tested. Specimens are to be prepared such that they overlap in the thickness direction so that the full plate thickness is tested.

2.7.6 Transverse bend specimens of rectangular section are to be prepared with the weld centred in the middle of the specimen as shown in *Figure 12.2.10 Transverse bend test specimens*. For material of thickness 12 mm or greater, the face and root bends may be substituted by side bend tests. Where there is a significant difference between the strength of the weld and base material, longitudinal bend specimens may be used. The weld reinforcement may be removed by grinding or machining prior to testing and the edges rounded to a radius not exceeding 10 per cent of the specimen thickness. Each specimen is to be bent through an angle of at least 180°. The bend test ratio is to be the lesser of the following:

(a)

$D_f = (D/t) + 1$

or

(b)

$D_f = 100/E_m$ (rounded up to the next whole number)

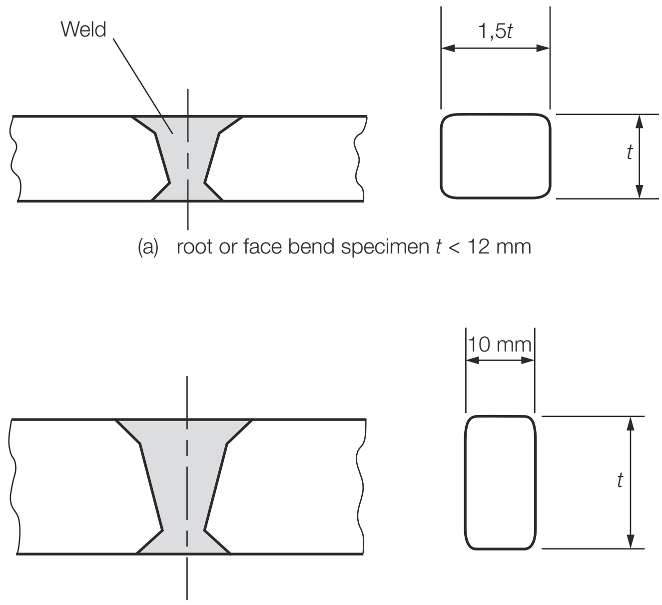
where

D_f = is the bend test ratio

(D/t) = is the value from *Table 11.3.3 Requirements for butt weld tests (covered electrodes)*, *Table 11.4.3 Requirements for butt weld tests (wire-flux combinations)* or *Table 11.8.2 Requirements for butt weld tests (all techniques)* in Chapter 11, as appropriate

E_m = is the minimum specified percentage elongation for the test material (based on a proportional gauge length of $5,65\sqrt{S_o}$’(’

2.7.7 Where the weld test is made between different material types, the requirements of *Ch 12, 2.7 Destructive tests for steel butt welds 2.7.8* are to be applied to the material with the lower toughness specification.



(a) root or face bend specimen t < 12 mm

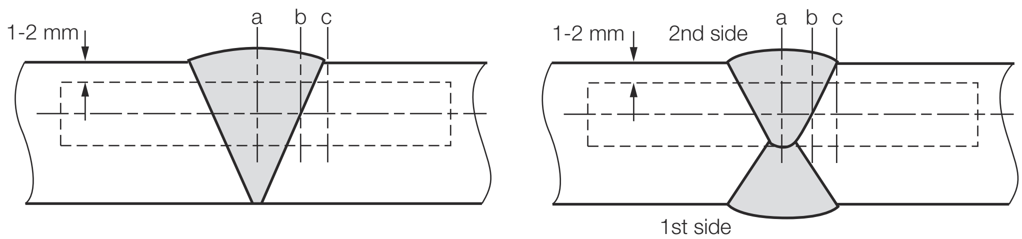
(b) side bend specimen t = material thickness

Figure 12.2.10 Transverse bend test specimens

2.7.8 For hull structural steels, impact test specimens are to be prepared from the locations shown in *Figure 12.2.11 Locations of V-notch for butt weld of normal heat input (heat input ≤ 50 kJ/cm)* or *Figure 12.2.12 Locations of V-notch for butt weld of high heat input (heat input > 50 kJ/cm)*, with the notch perpendicular to the plate surface and have the dimensions and

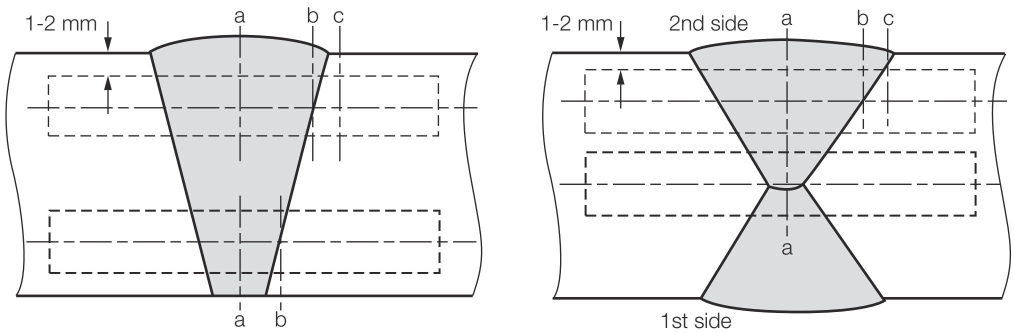
proportions in accordance with *Ch 2, 3 Impact tests*. Where more than one welding process or type of consumable has been used to make the weld, test specimens are also to be removed from these respective parts of the weld. Note that this does not apply to the welding process or consumables used solely to make the root or first weld run. Where the weld thickness exceeds 50 mm, an additional set of impact tests is required from the root area of the weld irrespective or whether different welding process or welding consumables are used as shown in *Figure 12.2.11 Locations of V-notch for butt weld of normal heat input (heat input ≤ 50 kJ/cm)* and *Figure 12.2.12 Locations of V-notch for butt weld of high heat input (heat input > 50 kJ/cm)*.

(a) $t \leq 50$ mm (1)



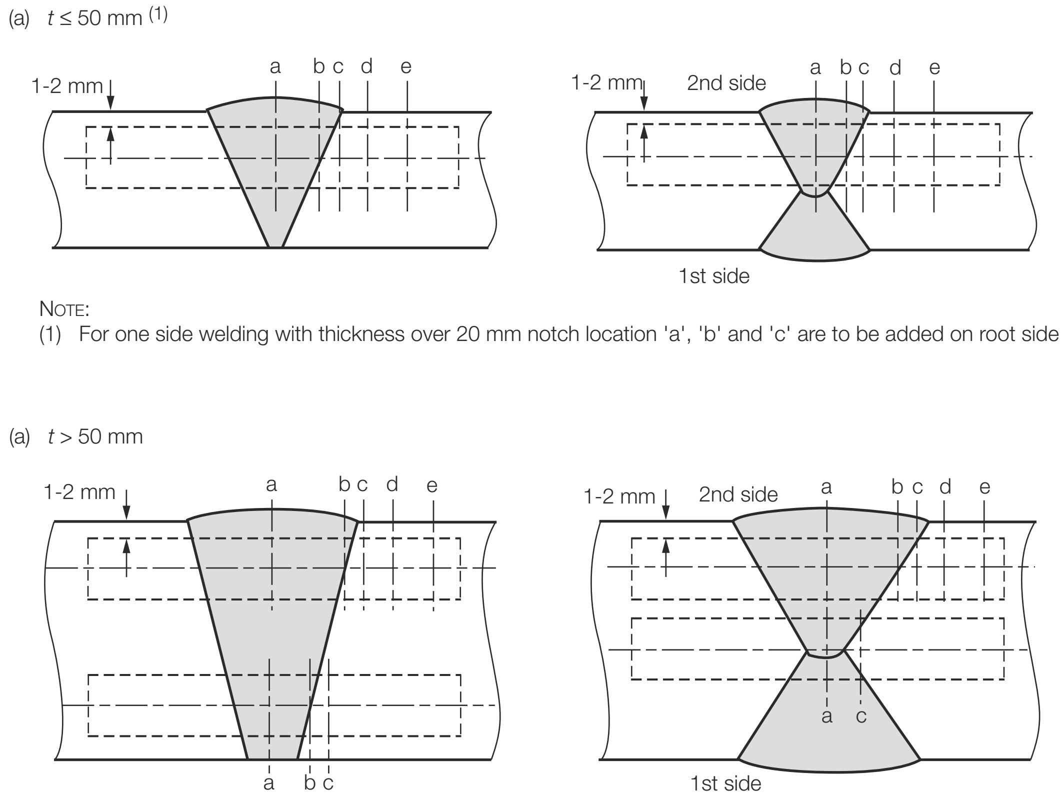
NOTE:
(1) For one side single run welding over 20 mm notch location 'a' is to be added on root side

(a) $t > 50$ mm



Notch locations:
a : centre of weld 'WM'
b : on fusion line 'FL'
c : in HAZ, 2mm from fusion line

Figure 12.2.11 Locations of V-notch for butt weld of normal heat input (heat input ≤ 50 kJ/cm)



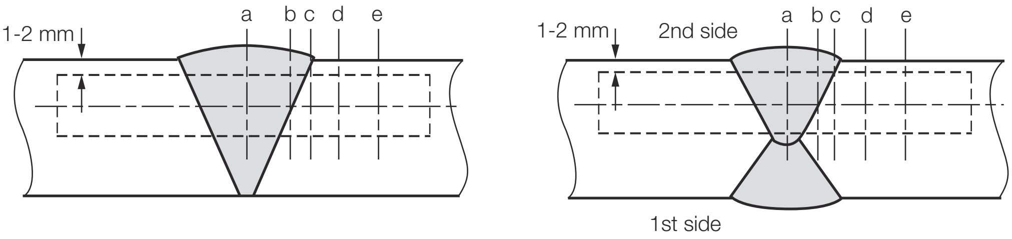
Notch locations:
a : centre of weld 'WM'
b : on fusion line 'FL'
c : in HAZ, 2 mm from fusion line
d : in HAZ, 5 mm from fusion line
e : in HAZ, 10 mm from fusion line in case of heat input > 200 kJ/cm

Figure 12.2.12 Locations of V-notch for butt weld of high heat input (heat input > 50 kJ/cm)

2.7.9 For offshore structures and pressure vessels, impact test specimens are not required to be notched at the FL + 10 mm location. Where more than one welding process or type of consumable has been used to make the weld, test specimens are to be removed from the respective areas of the weld. This does not apply to the process or consumables used solely to make the root or first weld run.

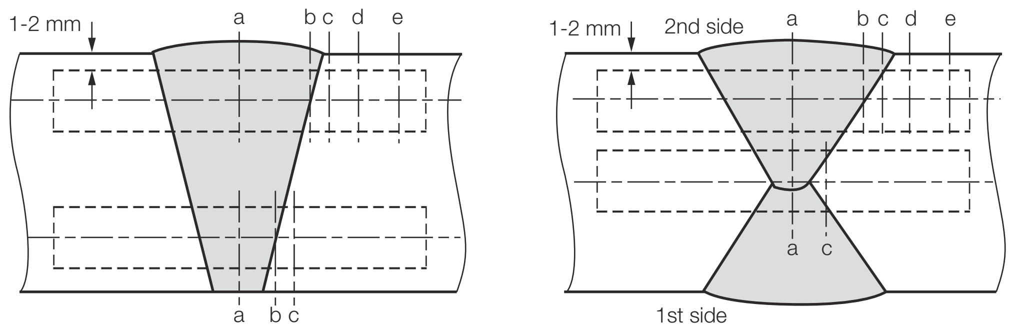
2.7.10 For pressure vessels and tanks employed in transportation of liquefied gases, Charpy impact test locations from the weld and heat affected zone are to be in accordance with *Figure 12.2.13 Locations of V-notch tests for butt welds intended for liquefied gas containment systems*.

(a) $t \leq 50$ mm, *see* Note



Note
For one side welding with thickness over 20 mm notch locations ‘a’, ‘b’ and ‘c’ are to be added on root side

(a) $t > 50$ mm



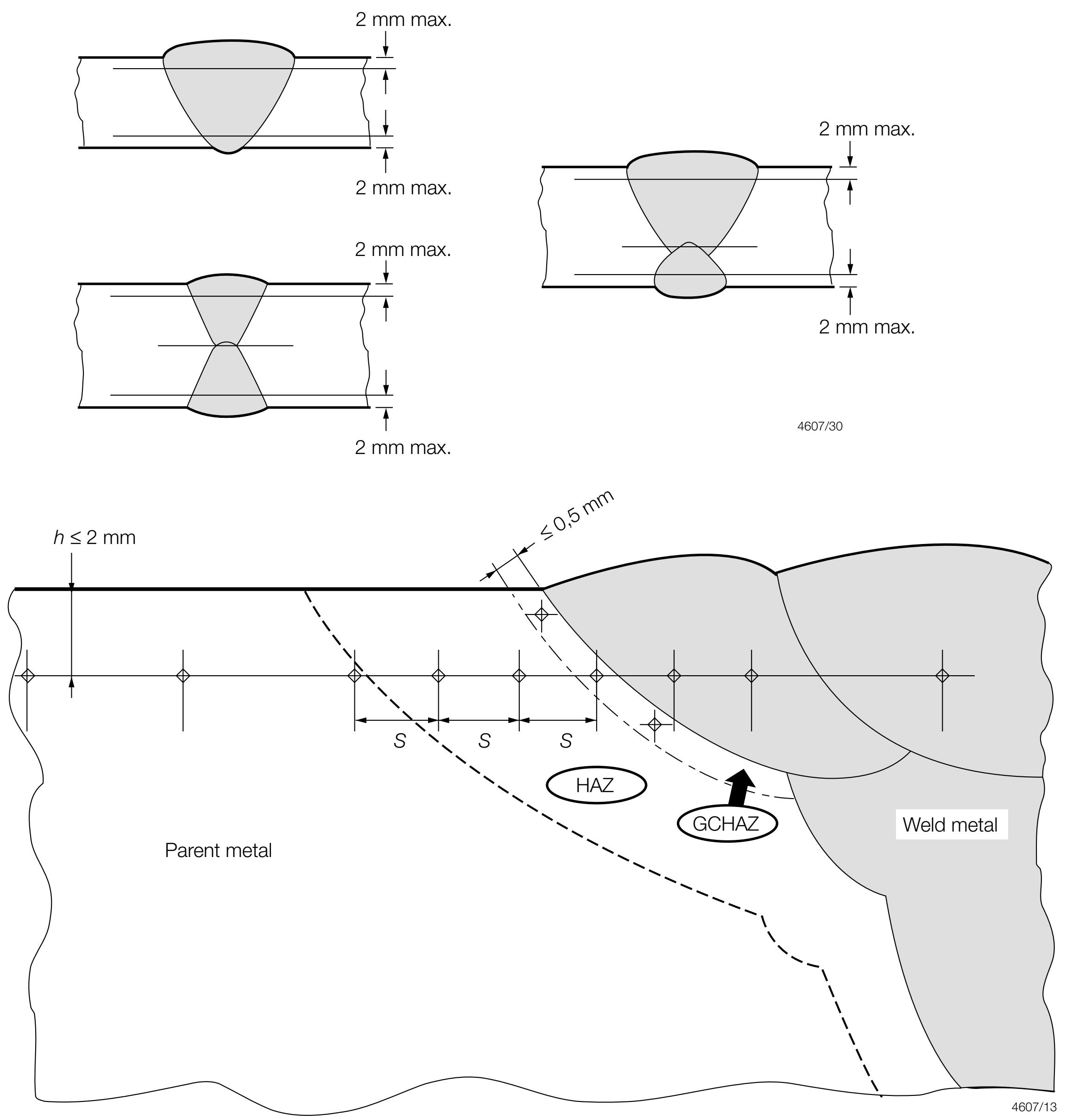
Notch locations:
a : centre of weld ‘WM’
b : on fusion line ‘FL’
c : in HAZ 1 mm from fusion line
d : in HAZ 3 mm from fusion line
e : in HAZ 5 mm from fusion line

Figure 12.2.13 Locations of V-notch tests for butt welds intended for liquefied gas containment systems

2.7.11 At least one macro examination specimen is to be removed from the test plate, near the end where welding started. The specimen is to include the complete cross-section of the weld and the heat affected zone and be prepared and etched to clearly reveal the weld runs and the heat affected zone. Examination is to be performed under a magnification of between x5 and x10.

2.7.12 A chemical analysis of the weld metal is to be performed on the macro specimen where approved welding consumables have not been used. The results are to comply with the limits given in the welding consumable specification.

2.7.13 A Vickers hardness survey is to be performed on the macro specimen taken from the weld start end of the test assembly in accordance with that shown in *Figure 12.2.14 Hardness testing locations for butt welds*, using a test load not in excess of 10 kg. For each row of indents, there are to be a minimum of 3 individual indentations in the weld metal, the heat affected zones (both sides) and the base metal (both sides). The recommended distance between indents is 1,0 mm, but the distance between indents should not be less than the minimum specified in ISO 6507/1.



HAZ	Heat affected zone
GCHAZ	Grain coarsened heat affected zone
S	Indentation spacing

Figure 12.2.14 Hardness testing locations for butt welds

2.8 Destructive tests for steel fillet welds

2.8.1 Fillet weld test assemblies are to be sectioned for destructive testing in accordance with *Figure 12.2.3 Fillet weld test assembly in plate* and as follows:

(a) two fracture tests;

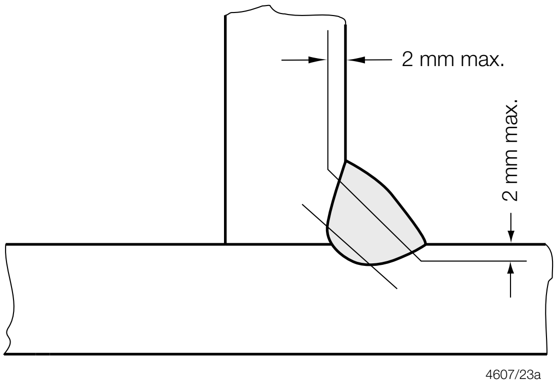
(b) three macro-sections;

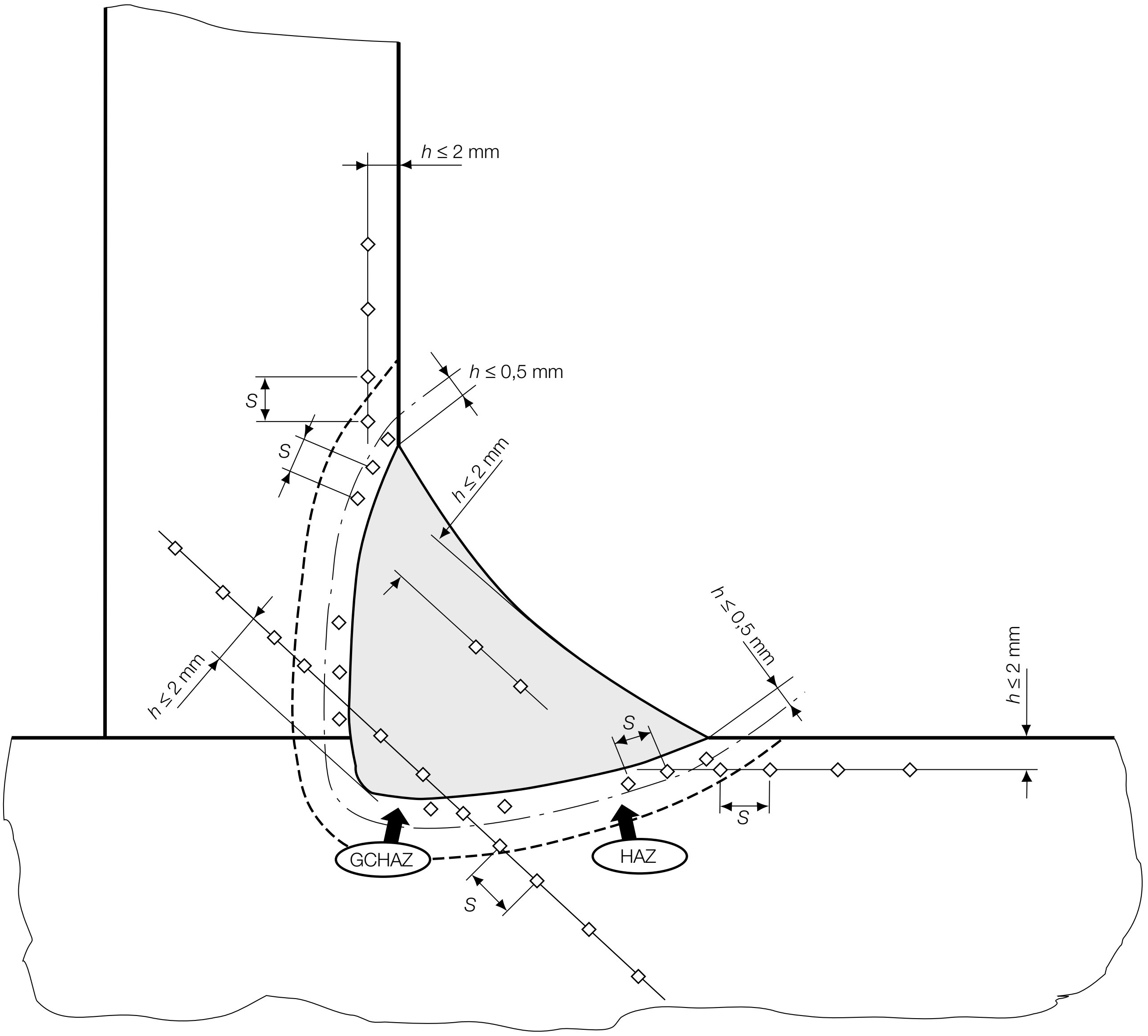
(c) one hardness survey.

2.8.2 Two fracture test specimens are to be removed from the test weld and are to be subjected to testing by bending the upright plate onto the through plate to produce fracture, as shown in *Figure 12.2.3 Fillet weld test assembly in plate*.

2.8.3 At least three macro examination specimens are to be removed from the test plate. The specimens are to include the complete cross-section of the weld and the heat affected zone and is to be prepared to clearly reveal the weld runs and the heat affected zone. One of the specimens is to include a weld stop/start position. Examination is to be performed under a magnification of between x5 and x10.

2.8.4 A Vickers hardness survey is to be performed on the macro specimen taken from the weld start end of the test assembly in accordance with that shown in *Figure 12.2.15 Hardness test locations for fillet welds*, using a test load not exceeding 10 kg.





HAZ	Heat affected zone
GCHAZ	Grain coarsened heat affected zone
S	Indentation spacing

Figure 12.2.15 Hardness test locations for fillet welds

2.9 Destructive tests for T, K, Y steel nozzle welds

2.9.1 Full penetration ‘T', ‘K’ and ‘Y’ joints for structural applications and nozzle welds for pressure vessels are to be sectioned for testing in accordance with *Figure 12.2.16 Location of macro-examination test specimens for T, K and Y joints* and tested as detailed below:

(a) three macro specimens;
(b) impact tests from the weld, fusion line and fusion line + 2 (where the material thickness permits);
(c) one hardness survey.

In addition, butt weld tests are to be performed in accordance with *Ch 12, 2.7 Destructive tests for steel butt welds*, using the same welding conditions, in order to verify acceptable weld and heat affected zone properties.

2.9.2 The impact tests are to be removed from the vertical (up) position ‘B’ in *Figure 12.2.16 Location of macro-examination test specimens for T, K and Y joints* and tested in accordance with *Ch 12, 2.7 Destructive tests for steel butt welds 2.7.8*.

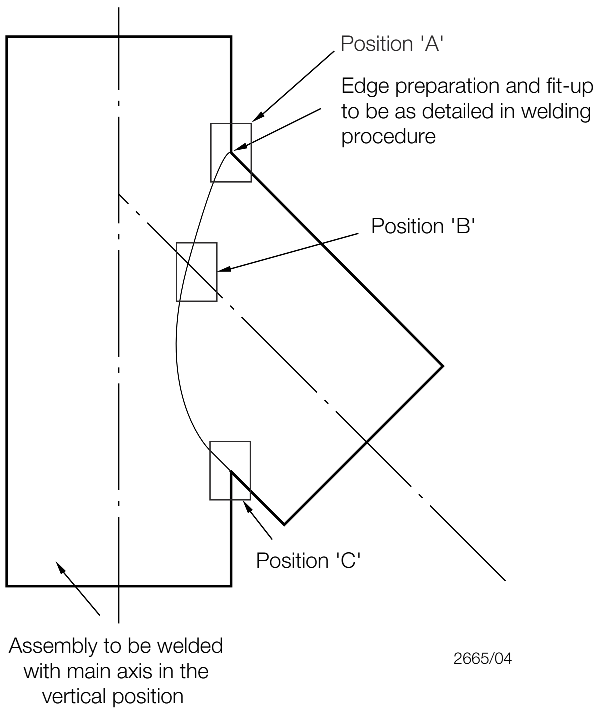
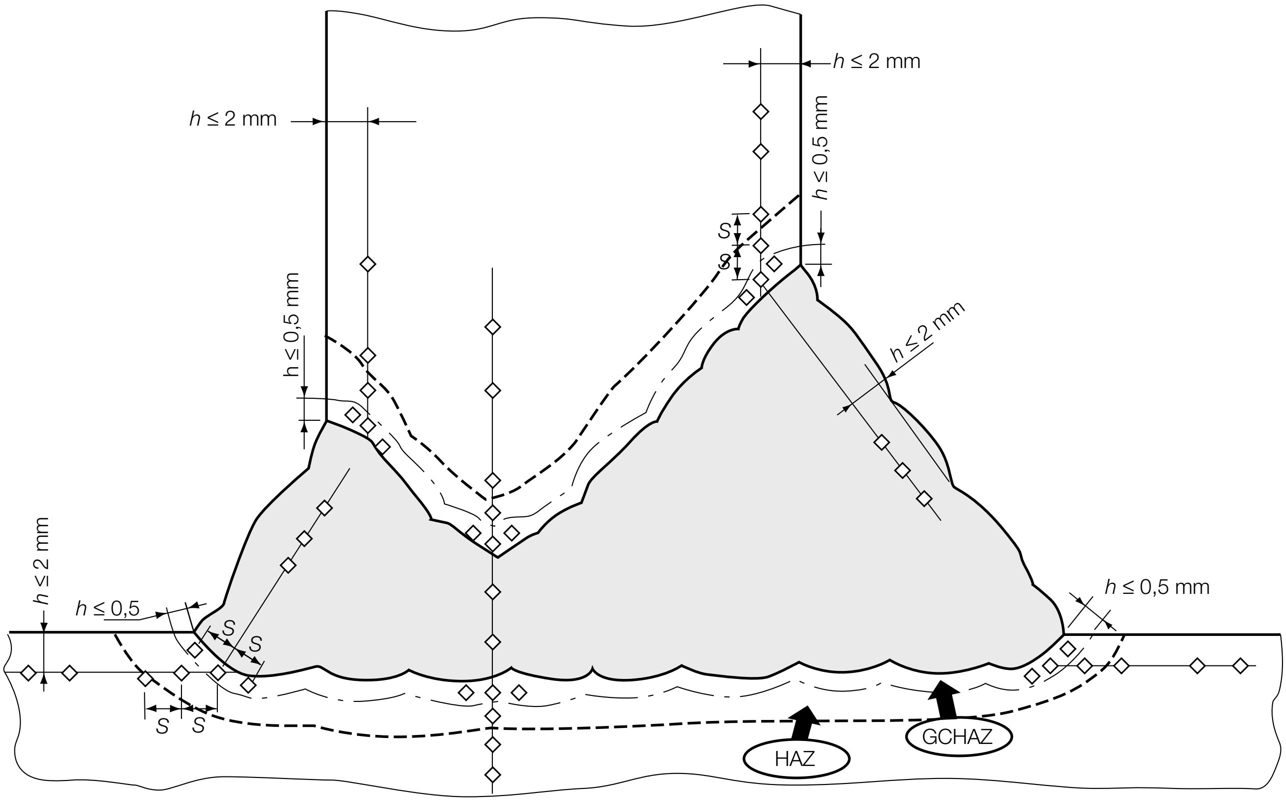


Figure 12.2.16 Location of macro-examination test specimens for T, K and Y joints

2.9.3 A Vickers hardness survey is to be performed on the macro-section removed from position ‘A’ or ‘C’ in accordance with that shown in *Figure 12.2.17 Hardness test locations for T, K and Y joints* using a test load not exceeding 10 kg.



HAZ Heat affected zone
GCHAZ Grain coarsened heat affected zone
S Indentation spacing

Figure 12.2.17 Hardness test locations for T, K and Y joints

2.10 Destructive tests for steel pipe branch welds

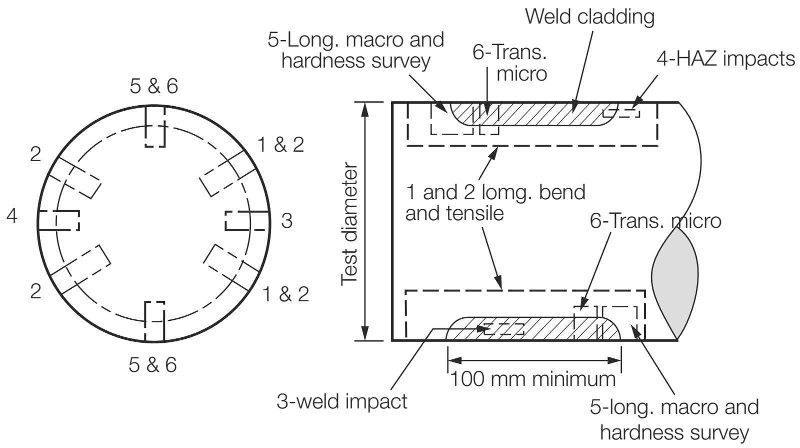
2.10.1 Pipe branch welds may be by either full penetration, partial penetration or fillet welded, depending on the application and the approved plans. Where these types of welded joints are used, tests are to be performed which simulate the construction conditions.

2.10.2 The test weld assembly is to simulate the smallest angle between the branch and main pipe and is to be subjected to macro-examination and hardness testing, as follows:

(a) For a branch weld that is full penetration, testing is to be performed in accordance with the requirements for 'T', 'K' and 'Y' joints in *Ch 12, 2.9 Destructive tests for T, K, Y steel nozzle welds*.
(b) For a branch weld that is either a partial penetration or fillet weld, testing is to be in accordance with the requirements for fillet welds in *Ch 12, 2.8 Destructive tests for steel fillet welds*.

2.11 Destructive tests for weld cladding of steel

2.11.1 Where weld cladding or overlay is allowed by *Ch 13 Requirements for Welded Construction*, and is considered as providing strength to the component to which it is welded, the type and location of test specimens are to be in accordance with *Figure 12.2.18 Type and location of test specimens for weld cladding*, except that micro-sections are not required. Impact tests may be omitted where the base material does not have specified impact properties. The longitudinal tensile and bend tests are to be tested in a similar manner to transverse specimens specified in *Ch 12, 2.7 Destructive tests for steel butt welds 2.7.2* and *Ch 12, 2.7 Destructive tests for steel butt welds 2.7.6*, respectively.



Test specimens
1 Longitudinaltensile test to include the weld metal, heat affected zone (HAZ) and base metal.
2 Longitudinal side bend test to include the weld metal, heat affected zone (HAZ) and base metal.
3 Weld metal Charpy V notch impact test.
4 HAZ Charpy impact test from Fusion Line and Fusion Line + 2 mm.
5 Longitudinal macro-section and hardness survey.
6 Transverse micro-section.

Note
In the case of shafts and pipes of circular section, the longitudinal direction is parallel to the centreline of the shaft or pipe axis.

Figure 12.2.18 Type and location of test specimens for weld cladding

2.11.2 Where the weld cladding is not considered as contributing to the strength of the component, but is required for corrosion or wear resistance, the type and location of test specimens are to be in accordance with *Figure 12.2.18 Type and location of test specimens for weld cladding*, except that tensile and impact tests are not required.

2.11.3 Where the weld cladding is applied for corrosion resistance, in addition to the above, weld metal analysis is to be performed on one of the micro-sections, on the final weld surface but 2 mm deep. The analysis is to be within the limits specified for the corrosion resistance required.

2.12 Mechanical test acceptance criteria for steels

2.12.1 **Longitudinal all weld metal tensile test:**

(a) In general, the longitudinal all weld tensile test is to meet the minimum properties specified in *Table 11.3.2 Requirements for deposited metal tests (covered electrodes)* or *Table 11.4.2 Requirements for deposited metal tests (wire-flux combinations)*, as appropriate to the grade of steel and welding process used in the test.

(b) Where the application is such that no consumable approvals are specified in *Ch 11 Approval of Welding Consumables*, the longitudinal all weld tensile test tensile is to meet the minimum properties specified for the base materials used in the test.

(c) For pressure vessels manufactured from carbon or carbon/manganese steels, the tensile strength from the longitudinal all weld tensile test is not to be less than the minimum specified for the plate material and is not to be more than 145 N/mm^2 above this value,*see Ch 13, 4.8 Mechanical requirements 4.8.3*.

(d) For tanks intended for liquefied gases, the weld metal strength may be lower than the minimum specified for the base metal provided that the application has design approval. In such cases the strength is not to be less than that specified in the approved design.

2.12.2 **Transverse tensile test:** The tensile strength measured from the transverse tensile test is not to be less than the minimum specified for the base material used in the test. For tanks intended for liquefied gases, a lower ultimate tensile may be accepted subject to design approval as in *Ch 12, 2.12 Mechanical test acceptance criteria for steels 2.12.1*.

2.12.3 **Bend tests:**

(a) In general, bend tests are to exhibit no defects exceeding 3,0 mm measured in any direction across the tension face of the specimen after being bent over the required diameter of former to the appropriate angle.

(b) Bend tests for pressure vessel applications are to exhibit no defects exceeding 3,0 mm measured along the specimen or 1,5 mm measured transverse to the specimen axis, after bending.
(c) In all cases, premature failure of the bend tests at the edges of the specimen is to not be cause for rejection unless these are associated with a weld defect.

2.12.4 **Impact toughness tests:**

(a) Impact test specimens for hull construction are to be tested at the temperature, and are to achieve the minimum impact energy, as specified in *Table 12.2.2 Impact test requirements for butt joints (t ≤ 50 mm) see Notes 1 and 2* and *Table 12.2.3 Impact test requirements for butt joints (t > 50 mm) see Notes 1 and 2* .
(b) Impact test specimens for applications other than hull construction are to be tested at the same temperature and achieve the same minimum energy values, as specified for the base materials used in the test.
(c) Impact test acceptance criteria are to be in accordance with the above unless the Rules applicable to the particular construction specify more stringent requirements.
(d) For quench and tempered steels, the required test temperature and absorbed energy are to be in accordance with that specified for the parent materials.

Table 12.2.2 Impact test requirements for butt joints (*t* ≤ 50 mm) *see* Notes 1 and 2

Grade of steel	Test temperature (°C) *see* Note 4	Value of minimum energy absorbed (J), *see* Note 4		
		Manual or semi-automatic welded joints		Automatically welded joints
		Downhand, Horizontal, Overhead	Vertical upward, Vertical downward	
A, *see* Note 3	20	47	34	34
B, *see* Note 3, D	0			
E	-20			
AH32, AH36	20			
DH32, DH36	0			
EH32, EH36	-20			
FH32, FH36	-40			
AH40	20		39	39
DH40	0			
EH40	-20			
FH40	-40			

Note 1. Steel with yield strength greater than 390 N/mm^2 is not permitted in thickness less than 50 mm, *see Table 3.3.1 Maximum thickness limits* in Chapter 3.

Note 2. These requirements are to apply to test piece of which butt weld is perpendicular to the rolling direction of the plates.

Note 3. For grade A and B steels average absorbed energy on fusion line and in heat affected zone is to be a minimum of 27 J.

Note 4. For Naval ships both the test temperature and value of minimum energy absorbed are to be those specified for the parent material.

Table 12.2.3 Impact test requirements for butt joints (*t* > 50 mm) *see* Notes 1 and 2

Grade of steel	Test temperature (ºC) *See* Note 2	Value of absorbed energy (J, min.), *see* Note 2		
		Manual or semi-automatic welded joints		Vertical upward, Vertical downward
		Downhand, Horizontal, Overhead	Automatically welded joints	

A	20	34	34	34
B	0	34	34	34
D	0	47	38	38
E	–20	47	38	38
AH32, AH36	20	47	41	41
DH32, DH36	0	47	41	41
EH32, EH36	–20	47	41	41
FH32, FH36	–40	47	41	41
AH40	20	50	46	46
DH40	0	50	46	46
EH40	–20	50	46	46
FH40	–40	50	46	46
EH47	–20	64	64	64
Note 1. These requirements are to apply to test piece of which butt weld is perpendicular to the rolling direction of the plates.				
Note 2. For the Naval ships, both the test temperature and value of minimum absorbed energy are to be those specified for the parent material.				

2.12.5 **Macro-examination:**The macro-section is to reveal an even weld profile blending smoothly with the base material. The weld dimensions are to be in accordance with the requirements of the pWPS and any defects present are to be assessed against the non-destructive examination acceptance criteria given in *Ch 12, 2.5 Non-destructive examination (NDE) 2.5.5*.

2.12.6 **Hardness surveys:** The maximum hardness value reported is not to exceed 350 Hv for steels with a specified minimum yield strength up to ≤420 N/mm^2, nor exceed 420 Hv for steels with a specified minimum yield strength in the range 420 N/mm^2 to 690 N/mm^2.

2.12.7 **Weld fracture or break tests (for pressure vessel test welds):** The faces of the broken fillet weld fracture or weld break test are to be examined for defects and assessed in accordance with the non-destructive acceptance criteria given in ISO 5817 Level B, except for excess convexity and excess throat thickness where Level C will apply.

2.13 Failure to meet requirements (Retests)

2.13.1 Where a tensile, bend or hardness specimen fails to meet requirements, further test specimens may be removed and tested in accordance with the requirements of *Ch 2, 1.4 Re-testing procedures 1.4.1*.

2.13.2 Where an impact specimen fails to meet requirements, a further set of three specimens may be removed and tested in accordance with the requirements of *Ch 2, 1.4 Re-testing procedures 1.4.4*.

2.13.3 Where a macro specimen reveals a defect that is planar in nature, the welding procedure test is to be considered as not satisfying the requirements and a new test assembly is required.

2.13.4 Where a macro specimen does not meet requirements as a result of a volumetric imperfection exceeding the permitted size, two additional specimens may be removed from the same test weld and examined. If either of these macro-sections also fails to satisfy the requirements, the welding procedure is to be considered as not having met the requirements.

2.13.5 If there is a single hardness value above the maximum values specified, additional hardness tests are to be carried out, either on the reverse of the specimen, or after sufficient grinding of the tested surface. None of the additional hardness values is to exceed the maximum hardness values specified, otherwise the welding procedure is to be considered as not having met the requirements.

2.13.6 Where there is insufficient material available in the welded test assembly to provide re-test specimens, subject to prior agreement with the Surveyor, a second assembly may be welded using the same conditions as the original test weld.

2.14 Test records

2.14.1 The procedure qualification record (PQR) is to be prepared by the manufacturer and is to include details of the welding conditions used in the test specified in *Ch 12, 2.2 Welding variables* and the results of all the non-destructive examinations and destructive tests, including re-tests.

2.14.2 Provided that the PQR lists all the relevant variables and there are no inconsistent features and the results satisfy the requirements, the PQR may be endorsed by the Surveyor as satisfying the requirement of the Rules, *see also Ch 12, 1.1 General 1.1.4*.

2.15 Range of approval

2.15.1 A welding procedure qualification test that has successfully met the requirements may be used for a wider range of applications than those used during the test.

2.15.2 Changes outside of the ranges specified are to require a new welding procedure test.

2.15.3 Other ranges of approval from those specified in this Section may be agreed with the Surveyor, provided that they are in accordance with recognised National or International Standards.

2.15.4 **Manufacturer.** A welding procedure qualified by a manufacturer is valid for welding in workshops under the same technical and quality management.

2.15.5 **Welding process and technique.** The welding process and welding techniques approved are to be those employed during the welding procedure qualification test. Where multiple welding processes are used, these are to be employed in the same order as that used in the welding procedure qualification test. However, it may be acceptable to delete or add a welding process where it has been used solely to make the first weld run in the root of the joint, provided back gouging or grinding of the root weld is specified on the WPS. For multi-process procedures, the welding procedure approval may be carried out with separate welding procedure tests for each welding process.

2.15.6 **Welding positions.** Approval for a test made in any position is restricted to that position. To qualify a range of positions, test assemblies are to be welded for the highest heat input position, and the lowest heat input position, and all applicable tests are to be made on those assemblies. The above excludes welding in the vertical position with travel in the downward direction which will always require separate qualification testing and only be acceptable for that position.

2.15.7 **Joint types.** A qualification test performed on a butt weld may be considered acceptable for fillet and partial penetration welds, provided the same welding conditions are used. The range of approval depending on the type of joint for butt welds is given in *Table 12.2.4 Range of approval for different types of butt joints*.

Table 12.2.4 Range of approval for different types of butt joints

Type of welded joint for test assembly				Range of approval
Butt welding	One side	With backing	A	A,C
		Without backing	B	A,B,C,D
	Both sides	With gouging	C	C
		Without gouging	D	C,D

2.15.8 **Range of material types:**

(a) A qualification test performed on one strength level of steel may be used to weld all similar materials with the same or lower specified minimum yield stress with the exception of the two-run (T) or high welding heat input (A) techniques where acceptance is limited to the strength level used in the test. Similarly, a qualification test performed on a steel with one toughness level may be considered acceptable for welding all similar materials with the same or three toughness grades lower specified minimum toughness level.

(b) A qualification test performed on H47 strength grade steels may be used to weld the steel of the same strength level or grade H40 and all lower toughness grades to that tested.

(c) For high strength quenched and tempered steels, for each strength level, welding procedures are considered applicable to the same and lower toughness grades as that tested. For each toughness grade, welding procedures are considered applicable to the same and one lower strength level as that tested. The approval of quenched and tempered steels does not qualify thermo-mechanically rolled steels (TMCP steels) and vice versa.

(d) For weldable C and C-Mn steel forgings, welding procedures are applicable to the same and lower strength level as that tested. The approval of quenched and tempered steel forgings does not qualify other delivery conditions and vice versa.

(e) For weldable C and C-Mn steel castings, welding procedures are applicable to the same and lower strength level as that tested. The approval of quenched and tempered steel castings does not qualify other delivery conditions and vice versa. Dissimilar materials. Where a qualification test has been performed using dissimilar materials, acceptance is to be limited to the materials used in the test.

2.15.9 **Thickness and diameter range:**

(a) For straight butt welds, the material thickness range to be approved is to be based on the thickness of the test piece and the type of weld as shown in *Table 12.2.5 Welding procedure thickness approval range - Butt welds*.

(b) For butt welds between plates of unequal thickness, the lesser thickness is the ruling dimension.

(c) For fillet welds and 'T' butt welds, *Table 12.2.5 Welding procedure thickness approval range - Butt welds* is to be applicable to both the abutting and through member thicknesses. In addition to the requirements of *Table 12.2.5 Welding procedure thickness approval range - Butt welds*, the range of approval of throat thickness '*a*' for fillet welds is to be as follows:

- single run: 0,75*a* to 1,5*a*
- multi-run: as for butt welds with multi-run (i.e. *a* =*t*)

(d) Notwithstanding any of the above, the approval of maximum thickness of base metal for any technique is to be restricted to the thickness of the test assembly if three of the hardness values in the heat affected zone are found to be within 25 Hv of the maximum permitted.

(e) The material diameter range to be approved is to be based on the diameter of the test piece and type of weld as shown in *Table 12.2.6 Diameter range approved*.

Table 12.2.5 Welding procedure thickness approval range - Butt welds

Test thickness, *see* Note 1 (*t* in mm)	Range approved	
	All multi-run butt welds and all fillet welds *see* Notes 3 and 4	All single-run or two-run two-run (T technique) butt welds
$t \leq 3$	*t* to 2*t*	0,7*t* to 1,1*t*
$3 < t \leq 12$	3 to 2*t*	0,7*t* to 1,1*t*
$12 < t \leq 100$	0,5*t* to 2*t*, *see* Note 2	0,7*t* to 1,1*t* *see* Note 5
$t > 100$	0,5*t* to 1,5*t*	0,7*t* to 1,1*t* *see* Note 5

Note 1. Where the test plates have dissimilar thickness, the thickness, *t*, is to be based on the minimum thickness for butt welds and the maximum thickness for fillet welds.

Note 2. Subject to a maximum limit of 150 mm.

Note 3. For multi process procedures, the recorded thickness contribution of each process is to be used as a basis for the range of approval of the individual welding process.

Note 4. For vertical down welding, the test piece thickness, *t*, is the upper limit of the range of application.

Note 5. For processes with heat input over 5,0 kJ/mm, the upper limit of the range of approval is to be 1,0 *t*.

Table 12.2.6 Diameter range approved

Diameter used for test, *see* Note 1	Range of diameters approved
$D \leq 25$ mm	0,5D to 2D
$D > 25$ mm	> 0,5D, *see* Note 2
Note 1. D is the outside diameter of the pipe or the smallest side dimension of rectangular hollow section. Note 2. Lower diameter range limited to 25 mm minimum.	

2.15.10 **Welding consumables:**

(a) For manual and semi-automatic welding used for the fill and capping weld runs, it may be acceptable to change the brand or trade name of the welding electrode or wire from that used in the test, provided the proposed alternative has the same or higher approval grading and the same flux type (e.g. basic low hydrogen, rutile, etc.) as used in that test.

(b) For the consumable used to make the root weld of full penetration butt welds made from one side only, no change in the type or trade name of the consumable or backing material is permitted. Alternative backing materials may be used provided they are equivalent to those used for approval. Where the approved backing material is a low hydrogen grade and the steel being welded requires a low hydrogen backing material, testing of the alternative backing material is to confirm compliance with the requirements of *Ch 11, 7 Consumables for use in one-side welding with temporary backing materials*.

(c) For processes with heat input over 5 kJ/mm, no change in the type or trade name of the consumable is permitted.

2.15.11 **Shielding gas.** For gas shielded welding processes, a change in shielding gas composition from that used in the test will require a new qualification test.

2.15.12 **Heat Input.** The upper limit of heat input approved is 25 per cent greater than that used in the test, or 5,5 kJ/mm, whichever is the smaller. With heat input over 5,0 KJ/mm, the upper limit is 10 per cent above that used in the test. In all cases, the lower limit of heat input approved is 25 per cent lower than that used in the test.

2.15.13 **Current type.** The current type used during the qualification test is to be the only type approved. Additionally, changes from or to pulsed current require new qualification tests.

2.15.14 **Preheat temperature.** The temperature used during the test is to be the minimum approved. Higher temperatures may be specified for production welds up to the maximum interpass temperature. Where hardness tests have been performed that exhibit results near the maximum permitted, an increase in preheat temperature is required when welding material of greater thickness than that used in the test.

2.15.15 **Interpass temperature.** The maximum interpass temperature recorded during qualification testing is to be the maximum approved. Lower temperatures may be specified for production welding, but no lower than the minimum preheat temperature.

2.15.16 **Post-weld heat treatment.** A qualification test performed with no post weld heat treatment is only acceptable for production welding where no heat treatment is applied. Where the qualification test has included a post weld heat treatment, this is to be applied to all welds made with the welding procedure. The average specified soak temperature may vary by up to 25°C from that tested.

2.15.17 **Shop primers.** Welding procedure qualification with shop primers qualifies welds without primer, but not vice versa.

2.16 Welding procedure specification (WPS)

2.16.1 A welding procedure specification (WPS) is to be prepared by the manufacturer detailing the welding conditions and techniques to be employed for production welding. The WPS is to be based on the conditions and variables used during the qualification test, and is to include all the ranges of the essential variables specified in *Ch 12, 2.2 Welding variables 2.2.1* and *Ch 12, 2.15 Range of approval*.

2.16.2 The WPS should reference the procedure qualification record upon which it is based and is to be approved by the Surveyor prior to commencing production welding.

Section 3
Specific requirements for stainless steels

3.1 Scope

3.1.1 The requirements of this Section relate to the group of steel materials classed as stainless steels and include austenitic and duplex grades and martensitic grades.

3.1.2 In all cases, welding procedure tests are to be performed generally in accordance with Section 2 with the specific requirements specified below.

3.2 Austenitic stainless steels

3.2.1 The requirements of this Section relate to the group of stainless steel materials that are austenitic at ambient and sub-zero temperatures, (e.g. 304L, 316L types), *see Table 3.7.1 Chemical composition* in *Ch 3 Rolled Steel Plates, Strip, Sections and Bars*.

3.2.2 Impact tests are to be performed from specimens removed from the weld metal. Tests in the heat affected zone are not required. The specimens are to achieve the minimum impact energy, as specified in *Table 11.8.2 Requirements for butt weld tests (all techniques)*. in *Ch 11 Approval of Welding Consumables*

3.2.3 Hardness tests are generally not required.

3.2.4 For cryogenic or corrosion resistant applications, the ferrite content in the weld cap region is to be measured and is to be in the range 2 to 10 per cent, with the exception of grades S 31245 and N 08904 where the content is to be nominally zero.

3.2.5 A qualification test performed on an austenitic grade may be considered acceptable for welding other austenitic steels with the same or lower level of alloying elements and the same or lower tensile strength.

3.2.6 A qualification test performed for cryogenic applications may be considered acceptable for chemical applications, but not vice versa.

3.3 Duplex stainless steels

3.3.1 The requirements of this Section relate to the group of stainless steel materials that have a ferritic-austenitic structure and are usually referred to as duplex or super duplex stainless steels (e.g. S 31803, S 32760).

3.3.2 Impact test specimens are to be removed from the weld and heat affected zone in accordance with *Ch 12, 2 Welding procedure qualification tests for steels* with the exception that impact test specimens notched at the FL + 10 mm location are not required. The specimens are to be tested at a temperature of –20°C or the minimum design temperature whichever is the lower and exhibit a minimum average energy of 40 J.

3.3.3 The corrosion resistance is to be maintained in the welded condition and the following tests are to be performed to demonstrate acceptable resistance, unless agreed otherwise.

(a) A sample is to be removed from the weld and heat affected zone for micro-structural examination and is to be suitably prepared and etched so that the microstructures of the weld and heat affected zones can be examined at a magnification of x200 or higher. The micro-structure of the weld and heat affected zone is to be examined, the percentage grain boundary carbides and intermetallic precipitates is to be reported.

(b) The ferrite content in the un-reheated weld cap and cap HAZ along with the weld root and root HAZ are to be measured and reported. The ferrite content is to be in accordance with *Table 12.3.1 Requirements for ferrite content and corrosion tests for duplex stainless steel test welds*. Where the intended construction is such that the corrosion medium is only in contact with one surface of the weld (i.e. the weld root), the ferrite determination need only be reported in that surface area.

(c) Corrosion testing is to be performed on samples removed from the weld such that both the weld and HAZ are included in the test. The critical pitting temperature is to be determined in accordance with ASTM G48 Method C and meet the requirements specified in *Table 12.3.1 Requirements for ferrite content and corrosion tests for duplex stainless steel test welds*. The cap and root surfaces are to be inspected for evidence of pitting and may require probing the surface with a needle. Pitting found on the ends of the specimen in the weld cross-section may be ignored. The use of the weight loss method for corrosion testing may be accepted subject to special consideration.

Table 12.3.1 Requirements for ferrite content and corrosion tests for duplex stainless steel test welds

Duplex Stainless Steel Material Grade	Weld and HAZ Ferrite content	Minimum Critical Pitting Temperature (CPT)
S 31260	30 to 70%	20°C
S 31803	30 to 70%	20°C
S 32550	35 to 65%	25°C
S 32750	35 to 65%	25°C
S 32760	35 to 65%	25°C

3.3.4 Where the test weld is between a grade of carbon steel and duplex stainless steel, the test requirements of *Ch 12, 3.3 Duplex stainless steels 3.3.3* and *Ch 12, 3.3 Duplex stainless steels 3.3.3* are not required and the ferrite content of the weld and the duplex heat affected zone are to be reported for information.

3.3.5 A qualification test performed on a duplex stainless steel grade may be considered acceptable for welding other duplex grades which have the same or less stringent mechanical or corrosion properties.

3.3.6 The range of heat input is not to vary by more than +10 per cent or –25 per cent from that used during testing.

3.4 Martensitic stainless steels

3.4.1 The requirements of this Section relate to the group of stainless steel materials that have a martensitic structure at ambient temperatures, *see Table 4.5.1 Typical chemical composition for steel propeller castings* in *Ch 4 Steel Castings*.

3.4.2 The results of the hardness survey results are to be reported for information purposes only.

3.4.3 A qualification test is considered acceptable only for the grade of material used in the test.

■ *Section 4*
Welding procedure tests for non-ferrous alloys

4.1 Requirements for aluminium alloys

4.1.1 The requirements for welding procedure qualification tests for aluminium alloys are to be in accordance with the general requirements of *Ch 12, 2 Welding procedure qualification tests for steels* with the following exceptions and specific requirements.

4.1.2 Non-destructive examination is to be performed in accordance with *Ch 12, 2.5 Non-destructive examination (NDE)* and the assessment of results is to be in accordance with *Table 12.4.1 Acceptance criteria for surface imperfections of aluminium alloys* and *Table 12.4.2 Acceptance criteria for internal imperfections of aluminium alloys*.

Table 12.4.1 Acceptance criteria for surface imperfections of aluminium alloys

Surface discontinuity	Classification according to ISO 6520-1	Acceptance criteria
Crack	100	Not permitted
Lack of fusion	401	Not permitted
Incomplete root penetration in butt joints welded from one side	4021	Not permitted
Surface pore	2017	$d \leq 0{,}1s$ or $0{,}1a$ max. 1,0 mm

Uniformly distributed porosity (*see* Note 1)	2012	≤ 0,5% of area
Clustered porosity	2013	Not permitted
Continuous undercut	5011	Not permitted
Intermittent undercut	5012	$h \leq 0{,}1t$ or 0,5 mm (whichever is the lesser)
Excess weld metal (*see* Note 2)	502	$h \leq 1{,}5$ mm + $0{,}1b$ or 6 mm (whichever is the lesser)
Excess penetration	504	$h \leq 4$ mm
Root concavity (*see* Note 2)	515	$h \leq 0{,}05t$ or 0,5 mm (whichever is the lesser)
Linear misalignment (*see* Notes 3 and 4)	507	$h \leq 0{,}2t$ or 2,0 mm (whichever is the lesser)

Symbols

a = nominal throat thickness of a fillet weld

b = width of weld reinforcement

d = diameter of a gas pore

h = height or width of an imperfection

s = nominal butt weld thickness

t = wall or plate thickness (nominal size)

Note 1. To be in accordance with EN ISO 10042.

Note 2. A smooth transition is required.

Note 3. The limits for linear misalignment relate to deviations from the correct position. Unless otherwise specified, the correct position is to be taken when the centrelines coincide.

Note 4. Dimensional tolerances not specified in these Rules are to be mutually agreed between the manufacturer and the Surveyor.

Table 12.4.2 Acceptance criteria for internal imperfections of aluminium alloys

Internal discontinuity	Classification according to ISO 6520-1	Acceptance criteria	
Crack	100	Not permitted	
Lack of fusion	401	Not permitted	
Incomplete penetration	402	Not permitted	
Single gas pore	2011	$d \leq 0{,}2s$ or $0{,}2a$ or 4 mm (whichever is the lesser)	
Linear porosity (*see* Note 2)	2014	Not permitted	
Uniformly distributed porosity (*see* Note 2)	2012	$0{,}5t$ to $3t$	≤ 1% of area
		> $3t$ to $12t$	≤ 2% of area
		> $12t$ to $30t$	≤ 3% of area
		> $30t$	≤ 4% of area
Clustered porosity (*see* Note 1)	2013	$dA \leq 15$ mm or wp (whichever is the lesser)	

Elongated cavity Wormhole	2015 2016	$l \leq 0{,}2s$ or $0{,}2a$ or 3 mm (whichever is the lesser)
Oxide inclusion (*see* Note 2)	303	$l \leq 0{,}2s$ or $0{,}2a$ or 3 mm (whichever is the lesser)
Tungsten inclusion	3041	$l \leq 0{,}2s$ or $0{,}2a$ or 3 mm (whichever is the lesser)
Copper inclusion	3042	Not permitted
Multiple imperfections in any cross-section	—	The sum of the acceptable individual imperfections in any cross-section is not to exceed $0{,}2t$ or $0{,}2a$ (whichever is the lesser)
Symbols		
a = nominal throat thickness of a fillet weld *d* = diameter of a gas pore *h* = height or width of an imperfection *s* = nominal butt weld thickness *t* = wall or plate thickness (nominal size), in mm *wp* = width of weld or width or height of cross-sectional area *dA* = diameter of area surrounding gas pores *l* = length of imperfection in longitudinal direction of weld		
Note 1. For this acceptance criterion, linear porosity is to be considered as three aligned gas pores in a length of 25 mm. Note 2. Porosity is to be determined in accordance with ISO 10042. The requirements for a single gas pore are to be met by all the gas pores within this circle. Systematic clustered porosity is not permitted.		

4.1.3 Acceptance of the mechanical tests is to be in accordance with *Ch 11, 9 Consumables for welding aluminium alloys*. Welding of the strain hardened and heat treatable aluminium alloys will generally result in a loss of tensile strength in the heat affected zone below that specified for the base materials and the tensile strength acceptance criteria to be applied is that specified for the material in the annealed or 'as fabricated' condition. Minimum values of tensile strength measured on the transverse tensile samples are given in *Table 12.4.3 Tensile strength requirements by grade for aluminium alloys*.

Table 12.4.3 Tensile strength requirements by grade for aluminium alloys

Parent material Grade (alloy designation)	Minimum tensile strength (N/mm^2)
5754	190
5086	240
5083	275
5383	290
5059	330
5456	290
6005A	170
6061	170
6082	170

4.1.4 Impact tests and hardness surveys are not required for aluminium alloys.

4.1.5 Four side bend tests may be used in place of root and face bends where the test thickness exceeds 12 mm, and longitudinal bend tests may be used instead of transverse tests where the test weld is between different grades of alloy. Bend

specimens are to be bent round a former in accordance with *Table 11.9.1 Requirements for butt weld tests* in Chapter 11, with the exception that the 6000 series alloys may be bent round a former with D/t = 7.

4.1.6 The ranges of approval to be applied to the WPS are to be as specified for steel in *Ch 12, 2.15 Range of approval* with the following exceptions:

(a) The welding positions approved are as detailed in *Table 12.4.4 Welding procedure approval, welding positions for aluminium alloys*.

(b) The aluminium alloys are grouped into three groups as follows:

- Group A: aluminium-magnesium alloys, with Mg content ≤3,5 per cent (alloy 5754).
- Group B: aluminium-magnesium alloys with 4 per cent ≤Mg ≤5,6 per cent (alloys 5059, 5083, 5086, 5383 and 5456).
- Group C: aluminium-magnesium-silicon alloys (alloys 6005A, 6061 and 6082).

For each group, the qualification made on one alloy qualifies the procedure also for the other alloys in the group, with equal or lower tensile strength after welding. The qualification made on group B alloys qualifies the procedure for Group A alloys also. Approval for the range of material grades is summarised in *Table 12.4.5 Welding procedure approval, aluminium material grades approved*.

(c) The qualification of a procedure carried out on a test assembly of thickness t is valid for the thickness range given in *Table 12.4.6 Range of qualification for parent material thickness*. In the case of butt joints between dissimilar thicknesses, t is the thickness of the thinner material. In the case of fillet joints between dissimilar thicknesses, t is the thickness of the thicker material. In addition to the requirements of *Table 12.4.6 Range of qualification for parent material thickness*, the range of the qualification of throat thickness of fillet welds, a, is given in *Table 12.4.7 Range of qualification of throat thickness for fillet welds*. Where a fillet weld is qualified by a butt weld test, the throat thickness range qualified is to be based on the thickness of the deposited weld metal.

(d) The range of shielding gas compositions approved is to be in accordance with *Table 11.9.2 Shielding gas compositions* in *Ch 11 Approval of Welding Consumables*.

(e) A change in the brand or trade name of the filler metal from that used in the test is acceptable, provided that the proposed consumable has the same or higher strength grading.

(f) A change in post-weld heat treatment or ageing is not permitted, except that for the heat treatable alloys, artificial ageing may give approval for prolonged natural ageing.

Table 12.4.4 Welding procedure approval, welding positions for aluminium alloys

Test Position		Positions Approved
Downhand	D	D
Horizontal-vertical	X	D, X
Vertical up	Vu	D, X, Vu
Overhead	O	D, X, Vu and O
Note Welding in vertical down (Vd) position is not recommended.		

Table 12.4.5 Welding procedure approval, aluminium material grades approved

Material used in qualification test	Material Grades approved				
5754	5754				
5086	5086	5754			
5083	5083	5086	5754		
5383	5383	5083	5086	5754	
5059	5059	5383	5083	5086	5754
5456	5456	5383	5083	5086	5754

6005A	6005A	6082	6061		
6082	6005A	6082	6061		
6061	6005A	6082	6061		
Note Approval includes all the different strained and tempered conditions in each case.					

Table 12.4.6 Range of qualification for parent material thickness

Thickness of test assembly, *t* (mm)	Range of qualification Multi pass welds	Range of qualification All single-run or two-run (T technique) butt welds
$t \leq 3$	0,5 to 2*t*	0,5*t* to 1,1*t*
$3 < t \leq 20$	3 to 2*t*	0,5*t* to 1,1*t*
$t > 20$	≥ 0,8*t*	0,5*t* to 1,1*t*

Table 12.4.7 Range of qualification of throat thickness for fillet welds

Throat thickness of test piece, *a* (mm)	Range of qualification
$a < 10$	0,75 *a* to 1,5 *a*
$a \geq 10$	≥ 7,5

4.2 Requirements for copper alloys

4.2.1 The requirements for welding procedure qualification tests for copper alloys are to be in accordance with the requirements for steel as given in *Ch 12, 2 Welding procedure qualification tests for steels* with the following exceptions and additions.

4.2.2 Impact tests on copper alloys are not required.

4.2.3 Hardness tests are not required for seawater service.

4.2.4 For the welding of cast copper alloys for propellers, the minimum tensile strength from the transverse tensile test is to be in accordance with *Table 12.4.8 Minimum transverse tensile strengths for welded copper alloy propellers* .

Table 12.4.8 Minimum transverse tensile strengths for welded copper alloy propellers

Alloy designation	Minimum tensile strength (N/mm^2)
CU 1	370
CU 2	410
CU 3	500
CU 4	550

4.2.5 Bend tests are to be performed over a diameter of former as detailed in *Table 12.4.9 Former diameters for bend testing of copper alloy welds*.

Table 12.4.9 Former diameters for bend testing of copper alloy welds

Alloy designation (*see Ch 9 Copper Alloys*)	Former diameter (*D*/*t*)
Cast propellers:	

CU1	4
CU2	4
CU3	6, *see* Note
CU4	6, *see* Note
Other short freezing range castings:	
Copper-Nickel 90/10	4
Copper-Nickel 70/30	4
Aluminium bronze	6
Wrought alloys (tubes and pipes):	
Copper-phosphorus	3
Aluminium-brass	3
90/10 Copper-nickel-iron	3
70/30 Copper-nickel-iron	3
Note Where the qualification tests for these alloys are subjected to post-weld heat treatment the former diameter may be increased to D/t = 10.	

4.2.6 The range of approval to be applied to the WPS is to be as specified in *Ch 12, 2.15 Range of approval* with the exception of the material grades which are detailed in *Table 12.4.10 Range of approval for copper alloy material grades*.

Table 12.4.10 Range of approval for copper alloy material grades

Category	Alloy grade used in the qualification test	Alloy grades approved
Propellers	CU1	CU1
	CU2	CU1 and CU2
	CU3	CU1, CU2 and CU3
	CU4	CU4 see Note 1
Tubes /pipes	90/10 Copper -Nickel-Iron	90/10 Copper -Nickel-Iron
	70/30 Copper -Nickel-Iron	70/30 Copper -Nickel-Iron and 90/10 Copper -Nickel-Iron
Tubes /pipes *see* Note 2	Copper-Phosphorus deoxidised - arsenical	Copper-Phosphorus deoxidised - arsenical
	Copper-Phosphorus deoxidised - non arsenical	Copper-Phosphorus deoxidised - non arsenical
	Aluminium-brass	Aluminium-brass
Note 1. Where a CU3 type welding consumable has been used for the qualification test, the range of approval may also include welding of CU3.		
Note 2. These grades have limited weldability and approval to weld is subject to the materials satisfying the requirements of *Table 9.3.1 Chemical composition of principal elements only* in Chapter 9.		

Section 5
Welder qualification tests

5.1 Scope

5.1.1 The requirements of this Section relate to qualification of welders involved in welded construction associated with ships, or other marine structures, and products or components intended for use on or in these structures.

5.1.2 The requirements relate to fusion welding processes that are designated as manual, semi-automatic or partly mechanised. Special consideration will be given to other welding processes adapted from these requirements.

5.1.3 Prior to commencing production welding, the welder is to have performed a qualification test that satisfies these requirements. It is the responsibility of the manufacturer to ensure that the welder possesses the required level of skill for the work to be undertaken.

5.1.4 The qualification of welders is to be documented by the manufacturer and the records are to be available for review by the Surveyor.

5.1.5 Welder qualification tests made in accordance with EN, ISO, JIS, ASME or AWS may be considered for acceptance provided that, as a minimum, they are equivalent to, and meet the technical intent of these Rules to the satisfaction of the Surveyor.

5.2 Welder qualification test assemblies

5.2.1 The welding of the welder qualification test assembly is to simulate, as far as practicable, the conditions to be experienced in production and be witnessed by the Surveyor. The test is to be carried out on a test assembly piece and not by way of production welding.

5.2.2 The test is to simulate, as far as practicable, the welding techniques and practices to be encountered during production welding. The test assembly is to be designed to test the skill of the welder and have the shape and dimensions appropriate to the range of approval required.

5.2.3 The inspection length of the test weld is to be such as to permit the removal of all the necessary test specimens and for plate tests, but in no case is to be less than 250 mm. The test assembly is to be set in one of the positions as shown in *Figure 12.2.4 Plate butt weld test positions* appropriate to the welding positions to be approved.

5.2.4 A welding procedure specification (WPS) is required for the execution of the qualification test and is to include the information specified in *Ch 12, 2.2 Welding variables 2.2.1*, as a minimum.

5.2.5 The test assembly is to be marked with a unique identification and the inspection length is to be identified prior commencing welding. For pipe welds, the whole circumference is to be considered as the inspection length.

5.2.6 During welding of the test assembly, the welding time is to be similar to that expected under production conditions. For manual or semi-automatic processes, at least one stop and re-start in the root and in the top surface layer is to be included in the inspection length and marked for future inspection.

5.2.7 During welding of the test assembly, minor imperfections may be removed by the welder by any method that is used in production, except on the surface layer.

5.2.8 The Surveyor may stop the test if the welding conditions are not correct or if there is any doubt about the competence of the welder to achieve the required standard.

5.3 Examination and testing

5.3.1 Each completed test weld is to be examined and tested in accordance with the requirements of *Table 12.5.1 Welder qualification test requirements*.

Table 12.5.1 Welder qualification test requirements

Examination type	Butt welds	Fillet welds	Pipe branch welds
Visual	100%	100%	100%
Surface crack detection	*See* Note 1	100%	100%

Radiography	100% *See* Notes 2 and 6	Not required	Not required
Bend tests	4 required *See* Notes 3 and 6	Not required	Not required
Fracture tests	Not required	1 required *See* Note 4	Not required
Macro	Not required	1 required *See* Note 4	4 required *See* Note 5

Note 1. Surface crack detection examination may be required by the Surveyor in order to clarify the acceptability of any weld feature.

Note 2. Radiography may be replaced by ultrasonic examination for carbon and low alloy steels where the thickness exceeds 8 mm.

Note 3. Bend tests are required for gas metal arc welding with solid wire (GMAW) and oxy-acetylene welding.

Note 4. The fracture test may be replaced with 4 macro sections equally spaced along the inspection length.

Note 5. Macro-sections are to be separated by 90° measured around the abutting pipe member.

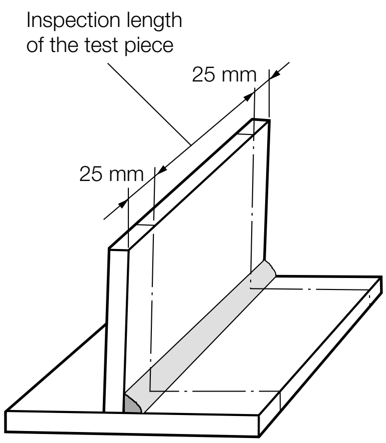
Note 6. Radiography and bend tests are required for tests in aluminium alloys.

5.3.2 Visual examination is to be performed in the as welded state prior to any other assessment.

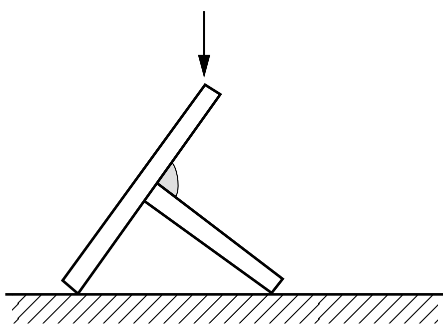
5.3.3 For plate butt welds, fracture testing may be used in place of radiography.

5.3.4 Where a backing strip has been used, it is to be retained for non-destructive examinations, but is to be removed prior to performing any bend or fracture tests.

5.3.5 Where fracture tests are required, they are to sample as much of the inspection length as practicable and the test assembly may be cut into several test specimens to achieve this. Testing is to be performed as shown in *Figure 12.5.1 Preparation and fracture testing of test specimens for a fillet weld in plate* or *Figure 12.5.2 Preparation and fracture testing of test specimens for a butt weld in plate*.



(a)
Sectioning into an even-numbered quantity of test specimens



(b)
Fracture testing
(The fillet weld may be notched if necessary)

4607/41

Figure 12.5.1 Preparation and fracture testing of test specimens for a fillet weld in plate

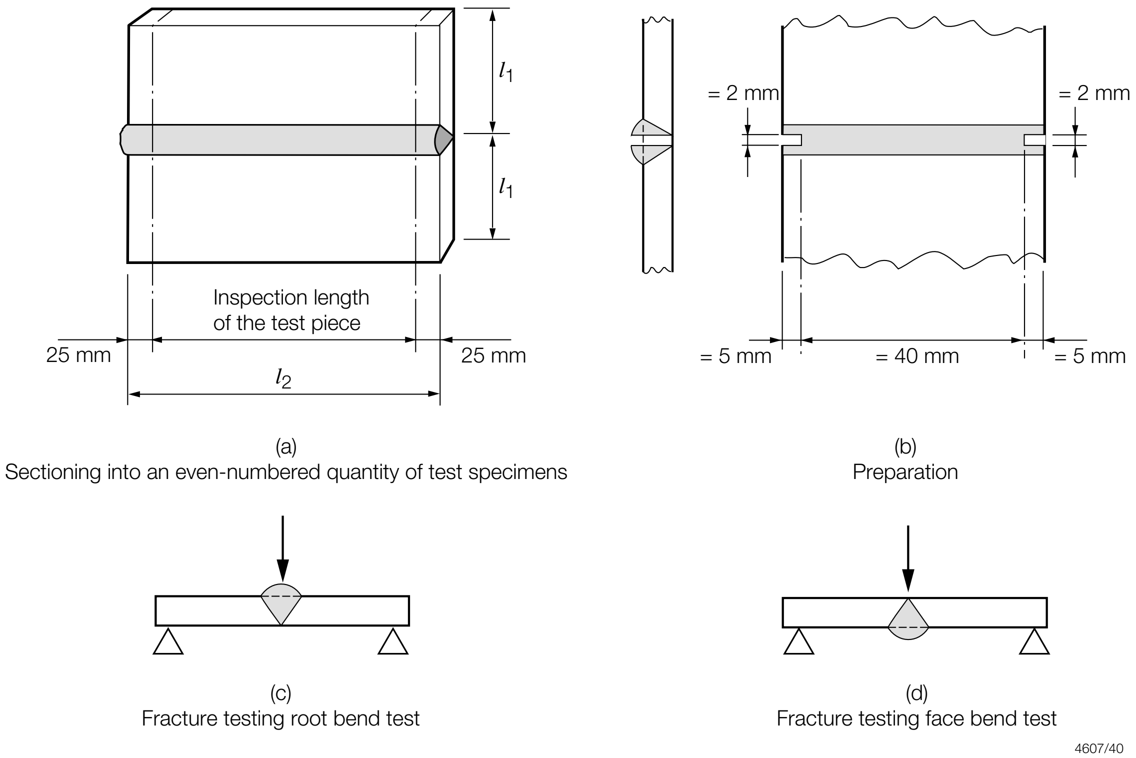


Figure 12.5.2 Preparation and fracture testing of test specimens for a butt weld in plate

5.3.6 For butt weld tests in aluminium alloys both radiography and bend tests are required.

5.3.7 When bend tests are required, 2 root and 2 face bends are to be tested and where the test thickness exceeds 12 mm, these may be substituted by 4 side bends specimens. The diameter of former to be used is to be in accordance with that specified for welding procedure qualification testing given in *Ch 12, 2.7 Destructive tests for steel butt welds 2.7.6*.

5.3.8 Where macro examination is required, the specimen is to be polished and etched to reveal the weld runs and heat affected zones, and be examined at a magnification between x5 and x10.

5.4 Acceptance criteria

5.4.1 The acceptance criteria are to be in accordance with *Ch 12, 2.5 Non-destructive examination (NDE) 2.5.5*.

5.4.2 Fracture tests and macro-sections are to be assessed in accordance with the non-destructive examination acceptance criteria.

5.4.3 Bend tests are considered acceptable if after bending through an angle of at least 180°, there are no defects on the tension side of the specimen greater than 3 mm in any direction.

5.5 Failure to meet requirements

5.5.1 Where a macro-section fails to meet requirements, one additional specimen may be removed from the test assembly and examined.

5.5.2 Where a bend or fracture test specimen fails to meet requirements, two additional specimens may be prepared from the same test assembly. If there is insufficient material, the welder may be permitted to weld an additional assembly to the same WPS, at the discretion of the Surveyor.

5.5.3 Where any of the additional test specimens fails to satisfy the requirements, the test will be considered as not meeting the requirements.

5.5.4 Where a test fails to comply with the acceptance criteria, the welder may be permitted to weld a second test piece. If this does not meet requirements, the welder is to be considered as not being capable of achieving the requirements.

5.6 Range of approval

5.6.1 Upon successful completion of all the necessary examinations and tests, the welder is to be considered qualified. The essential variables and the range of welding conditions for which the welder is considered approved are specified in the following paragraphs.

5.6.2 Welding variables such as preheat, interpass temperature, heat input and current type are not considered welder qualification variables. However, if the WPS used for testing specify these, they are to be included in the test and the welder is expected to follow the specific instructions.

5.6.3 Where the WPS used for the welder qualification test specifies post-weld heat treatment, this need not be applied to the test weld unless bend tests are required and the material exhibits low ductility in the as welded condition.

5.6.4 The qualification test performed by a manufacturer is only applicable to workshops under the same technical control and quality system as that used for the test.

5.6.5 The welding process used in the qualification test is the process approved. However, it is possible for the welder to use more than one process in the test and the range of approval that may be applied to each will be within the limits of the essential variables appropriate to the part of the test where each welding process was used.

5.6.6 Material types are to be grouped as shown in *Table 12.5.2 Welder qualification materials groupings* for welder qualifications. A qualification test performed on one material from a group will permit welding of all other materials within the same group. In addition, qualification on one group of materials may confer approval to weld other groups as shown in *Table 12.5.3 Welder qualification, range of approval for material groups*.

Table 12.5.2 Welder qualification materials groupings

Material group	Material description	Typical LR Grades	Rules for Material references
WQ 01	Low carbon unalloyed,	A, B, D and E	*Ch 3, 2 Normal strength steels for ship and other structural applications*
	C/Mn, or	AH to FH32 and 36	*Ch 3, 3 Higher strength steels for ship and other structural applications*
	Low alloyed steels (Re ≤ 360 N/mm^2)	Boiler 510FG and lower	*Ch 3, 4 Steels for boilers and pressure vessels*
		LT-AH to FH32 and 36	*Ch 3, 6 Ferritic steels for low temperature service*
		U1 and U2	*Ch 3, 9 Bars for welded chain cables* and *Ch 10 Equipment for Mooring and Anchoring*
		Steel castings	*Ch 4, 2 Castings for ship and other structural applications* , *Ch 4, 3 Castings for machinery construction*, *Ch 4, 6 Castings for boilers, pressure vessels and piping systems* and *Ch 4, 7 Ferritic steel castings for low temperature service*
		Steel pipes	*Ch 6, 2 Seamless pressure pipes*, *Ch 6, 3 Welded pressure pipes*, *Ch 6, 4 Ferritic steel pressure pipes for low temperature service* and*Ch 6, 6 Boiler and superheater tubes*
WQ 02	Cr-Mo, or	13CrMo45 and 11CrMo910	*Ch 3, 4 Steels for boilers and pressure vessels*
	Cr-Mo-V creep resisting steels	1Cr½Mo and 2¼Cr1Mo	*Ch 4, 6 Castings for boilers, pressure vessels and piping systems* and *Ch 6, 2 Seamless pressure pipes*, *Ch 6, 3 Welded pressure pipes* and *Ch 6, 6 Boiler and superheater tubes*

		½Cr½Mo¼V	*Ch 4, 6 Castings for boilers, pressure vessels and piping systems* and *Ch 6, 2 Seamless pressure pipes*
WQ 03	High strength fine grained,	AH to FH40 to 69	*Ch 3, 3 Higher strength steels for ship and other structural applications* and *Ch 10 Equipment for Mooring and Anchoring*
	Normalised or quenched, or	LT-AH to LT-FH40	*Ch 3, 6 Ferritic steels for low temperature service*
	Tempered structural steels (2,0 – 5% Ni, with Re > 360 N/mm^2)	1½ , 3½ Ni steels and castings	*Ch 3, 6 Ferritic steels for low temperature service*, *Ch 4, 7 Ferritic steel castings for low temperature service* and *Ch 6, 4 Ferritic steel pressure pipes for low temperature service*
		U3, R3, R3S and R4	*Ch 3, 9 Bars for welded chain cables*and *Ch 10 Equipment for Mooring and Anchoring*
WQ 04	Ferritic, or martensitic stainless steels (12 to 20% Cr)	13% Cr (martensitic)	*Ch 4, 5 Castings for propellers* (martensitic)
WQ 05	Ferritic low temperature steels	5Ni and 9Ni	*Ch 3, 6 Ferritic steels for low temperature service*
WQ 011	Ferritic-austenitic stainless steels,	304, 316, 317, 321 and 347	*Ch 3, 7 Austenitic and duplex stainless steels* and *Ch 8 Aluminium Alloys*
	Austenitic stainless steels, or Cr-Ni steels	S31260, S31803, S32550 and S32750	*Ch 4, 8 Stainless steel castings* and *Ch 6, 5 Stainless steel pressure pipes*
WQ 22a	Aluminium alloy – Non-heat treatable Mg < 3,5%	5754	*Ch 8 Aluminium Alloys*
WQ 22b	Aluminium alloy – Non-heat treatable 3,5% < Mg < 5,6%	5083 and 5086	*Ch 8 Aluminium Alloys*
WQ 23	Aluminium alloy – Heat treatable	6005-A, 6061 and 6082	*Ch 8 Aluminium Alloys*
WQ 30	Copper alloys for propellers – Manganese bronze	Cu1	*Ch 9, 1 Castings for propellers*
WQ 31	Copper alloys for propellers – Nickel – manganese bronze	Cu2	*Ch 9, 1 Castings for propellers*
WQ 32	Copper alloys for propellers – Nickel – aluminium bronze	Cu3	*Ch 9, 1 Castings for propellers*
WQ 33	Copper alloys for propellers – Manganese-aluminium bronze	Cu4	*Ch 9, 1 Castings for propellers*
WQ 34	Copper alloys for tubes – Copper phosphorus	Deoxidised – non-arsenical and arsenical	*Ch 9, 3 Tubes*
WQ 35	Copper alloys for tubes – Aluminium brass	Aluminium brass	*Ch 9, 3 Tubes*
WQ 36	Copper alloys for tubes – Copper – nickel- iron	70/30 Cu/Ni and 90/10 Cu/Ni	*Ch 9, 3 Tubes*

Table 12.5.3 Welder qualification, range of approval for material groups

Material Group used for testing	Material groups approved to weld			
WQ 01	WQ 01			
WQ 02	WQ 01	WQ 02		
WQ 03	WQ 01	WQ 02	WQ 03	
WQ 04	WQ 01	WQ 02	WQ 04	
WQ 05	WQ 05			
WQ 11	WQ 11	WQ 05, *see* Note	WQ 04, *see* Note	
WQ 22a	WQ 22a	WQ 22b		
WQ 22b	WQ 22a	WQ 22b		
WQ 23	WQ 22a	WQ 22b	WQ 23	
WQ 30	WQ 30	WQ 31	WQ 32	WQ 33
WQ 31	WQ 30	WQ 31	WQ 32	WQ 33
WQ 32	WQ 30	WQ 31	WQ 32	WQ 33
WQ 33	WQ 30	WQ 31	WQ 32	WQ 33
WQ 34	WQ 34	WQ 35		
WQ 35	WQ 34	WQ 35		
WQ 36	WQ 36			
Note Provided an austenitic welding consumable compatible with material group WQ 11 is used.				

5.6.7 A qualification test performed on one thickness will confer approval to weld other thicknesses as specified in *Table 12.5.4 Welder qualification, range of approval for material thickness*. Where welding is required between materials of different thickness, the reference thickness for approval purposes is to be the lesser thickness.

Table 12.5.4 Welder qualification, range of approval for material thickness

Material type	Test piece thickness (mm)	Range approved, *see* Note (mm)
Steel and copper alloys	$t \leq 3$	t to $2t$
	$3 < t \leq 12$	3,0 to $2t$
	$t > 12$	$\geq 5,0$
Aluminium alloys	$t \leq 6$	0,5 t to $2t$
	$t > 6$	≥ 6
Note For oxy-acetylene welding the maximum thickness is limited to 1,5 t.		

5.6.8 A qualification test performed on plate confers approval to weld on pipes having an outside diameter greater than 500 mm in a fixed position (*see Table 12.5.5 Welder qualification, diameter range of approval for pipes and hollow sections* and *Table 12.5.6 Welding position ranges for welder qualification*).

Table 12.5.5 Welder qualification, diameter range of approval for pipes and hollow sections

Material type	Test piece diameter (mm)	Range approved (mm)
Steel and copper alloys	$D \leq 25$	D to $2D$
	$25 < D \leq 150$	$0{,}5D$ to $2D$, *see* Note 1
	$D > 150$	$\geq 0{,}5D$
	Plate, *see* Note 2	≥ 500
Aluminium alloys	$D \leq 125$	$0{,}25D$ to $2D$
	$D > 125$	$\geq 0{,}5D$
	Plate, *see* Note 2	≥ 500

Note 1. Subject to 25 mm minimum diameter.

Note 2. Plate qualification will approve welding on pipes greater than 150 mm diameter when the pipe is rotated.

5.6.9 A qualification test performed using a specific diameter of pipe will give approval to weld other diameters as shown in *Table 12.5.5 Welder qualification, diameter range of approval for pipes and hollow sections*. For branch welds, the diameter upon which approval is based is to be the branch member.

5.6.10 A qualification test performed on a butt weld may be considered as giving approval for fillet welds.

5.6.11 A butt qualification test welded from one side, with the root unsupported (i.e. no backing), will give approval for welds made from both sides with or without back gouging or grinding, but not vice versa.

Table 12.5.6 Welding position ranges for welder qualification

Test weld conditions		Positions qualified			
Type of weld	Test position	Plate		Pipe, *see* Note 1	
		Butt weld	Fillet weld	Butt weld	Fillet weld
Plate butt, *see* Note 5	D	D	D	D	D
	X	D,X	D,X	D	D,X
	Vu	D, Vu	D, X, Vu	D	D, Vu
	Vd	Vd	Vd	–	–
	O	D, X, Vu, O	D, X, Vu, O	D	D, X, Vu, O
Plate Fillet, *see* Note 5	D	–	D	–	D
	X	–	D,X	–	D,X
	Vu	–	D, X, Vu	–	D, X, Vu
	Vd	–	Vd	–	–
	O	–	D, X, Vu, O	–	D, X, Vu, O

Pipe butt	D	D	D,X	D	D,X
	X	D,X	D,X	D,X	D,X
	D+Vu+O, *see* Note 3	D, Vu, O	D, X, Vu, O	D, Vu, O	D, X, Vu, O
	D+Vd+O, *see* Notes 2 and 3	Vd	Vd	Vd	Vd
	Axis at 45°, *see* Note 4, Travel Vu	D, X, Vu, O	D, X, Vu, O	D, X, Vu, O	D, X, Vu, O
	Axis at 45°, *see* Notes 2, 3 and 4, Travel Vd	Vd	Vd	Vd	Vd
Pipe fillet	D	–	D	–	D
	X	–	D, X	–	D, X
	D+Vu+O *see* Note 3	–	D, X, Vu, O	–	D, X, Vu, O
	D+Vu+O *see* Note 3	–	Vd	–	Vd

Note 1. Pipe D position means pipe in horizontal position and rotated, *see Figure 12.2.5 Pipe butt weld test positions* and *Figure 12.2.7 Pipe fillet weld test positions*.

Note 2. Vd position not usually recommended for pipe welds less than 500 mm diameter.

Note 3. Pipe fixed with axis in the horizontal position (e.g. ASME 5G).

Note 4. Pipe fixed with axis at 45° to the horizontal (e.g. ASME 6G).

Note 5. Plate qualification tests confers approval to weld pipes with diameter greater than 500 mm.

5.6.12 A qualification test performed in one position will give approval to weld in other positions as shown in *Table 12.5.6 Welding position ranges for welder qualification*.

5.6.13 For manual metal arc welding with covered electrodes, a qualification test performed using an electrode with one type of coating will only be approved for welding with that type of coating. However, a qualification test performed using a basic low hydrogen type coating will confer approval to use electrodes with rutile coatings.

5.6.14 For gas shielded welding processes that use a single component shielding gas, no change to the gas composition is permitted from that tested. Where the test has used a two component shielding gas, a change in the ratio of component gases is permitted, provided that one of the components is not reduced to zero. Where the test has used a three component shielding gas, changes are permitted in the ratio of component gases and the gas with the smallest ratio may be reduced to zero, provided this does not change the shielding gas from an active one to an inert one or vice versa. In addition, where a change in shielding gas composition requires a different welding method or technique to be employed, a new qualification test will be required.

5.6.15 A change of welding flux from that used for the test is permitted.

5.7 Welders qualification certification

5.7.1 All the relevant conditions used during the test are to be entered on the welder's qualification certificate along with the permitted range of approval.

5.7.2 If the Surveyor is satisfied that the welder has demonstrated the appropriate level of skill and all tests are satisfactory, the Surveyor will endorse the certificate verifying that the details contained on it are correct and that the test welds were prepared, welded and tested in accordance with the specified Rules, Codes or Standards.

5.7.3 The welder is considered to be approved for an initial validity period of 2 years. The welder is considered to have retained the qualification subject to the manufacturer confirming every 6 months that the welder has used the welding process with acceptable performance in the preceding 6 months.

5.7.4 After 2 years, the Surveyor may extend the validity of the approval for another period of two years provided that records or documented evidence is made available confirming acceptable welding performance, within the original range of approval, without a break exceeding 6 months. The Surveyor will signify acceptance of the extension to the validity by endorsing the certificate.

5.7.5 Where there is any reason to question the welder's ability, or there is a lack of continuity in the use of the welding process, or insufficient recorded evidence of acceptable weld performance, the welder is to perform a new qualification test.

5.7.6 Where the manufacturer has existing welders that have previously performed qualification tests, these may be considered for acceptance provided they satisfy the above requirements and the tests have been performed in the presence of an independent examiner that is acceptable to the Society.

5.7.7 Not withstanding the above, the Surveyor may at any time request a review of a welder's qualification records. If there is any reason for doubt concerning the skill of the welder, the Surveyor may withdraw the qualification and require a re-qualification test to be performed.

■ *Section 6*
Qualification of friction stir welding of aluminium alloys

6.1 Scope

6.1.1 The requirements of this Section relate to the Friction Stir Welding (FSW) of aluminium alloys. These requirements include requirements for verification of welding equipment, welding procedures, qualification of welding procedures and qualification of welding operators.

6.2 Welding equipment

6.2.1 Welding equipment (e.g. welding machines and FSW tools) is to be capable of producing welds that meet the specified acceptance levels.

6.2.2 Welding equipment is to be maintained in a good condition and is to be repaired or adjusted when necessary.

6.2.3 After installation of new or refurbished equipment, appropriate tests are to be performed to verify that the equipment functions correctly.

6.3 Weld procedures

6.3.1 This Section defines the requirements for welding procedures to be applied for FSW of aluminium alloys.

6.3.2 Manufacturers are to prepare a preliminary welding procedure specification (pWPS) defining procedures for how FSW is to be conducted.

6.3.3 A pWPS is to comply with the requirements of ISO 25239-4.

6.3.4 Qualification of a pWPS is achieved by conducting weld procedure qualification tests in accordance with ISO 25239-4. Minimum acceptance criteria for destructive tests are to be in accordance with these Rules. Reporting of the qualification tests are to be in accordance with ISO 25239-4.

6.3.5 Provided that the procedure qualification record lists all the relevant variables and there are no inconsistent features and the results satisfy the requirements, the procedure qualification record may be endorsed by the Surveyor as satisfying the requirement of the Rules.

6.3.6 A welding procedure specification (WPS) is to be prepared after the procedure qualification test report has been endorsed by the Surveyor.

6.3.7 For welding procedure specifications, the range of approval is to be limited as follows:

(a) **Manufacturer**. A welding procedure qualified by a manufacturer is valid for welding in workshops under the same technical and quality management.
(b) **Range of material type**. Approval is restricted to the specific aluminium grade and supply condition used in the qualification test.
(c) **Thickness**. Approval is restricted to the thickness of the test piece in the qualification test.
(d) **Joint types**. The joint types approved are to be those from the welding procedure qualification test only.

(e) **Welding tool**. Approval is restricted to the specific design of welding tool employed during the qualification test.

(f) **Other**. A range of approval for any other variables will be subject to special consideration.

6.4 Qualification of welding operators

6.4.1 Welding operators are to be qualified in accordance with ISO 25239-3.

6.4.2 Weldeing operators are to be suitably trained and will be required to demonstrate a knowledge of FSW and have a working knowledge of the welding installation. Knowledge of the FSW process may be demonstrated by exams passed during the training period. Demonstration of a working knowledge of the welding installation will be subject to the Surveyor's satisfaction.

6.4.3 Qualification of welding operators is to be by welding tests as specified in ISO 25239-3 or by conducting weld procedure qualification tests.

6.4.4 Upon successful completion of all necessary examination and tests, the welding operator is to be considered qualified. The range of qualification is to be as specified in ISO 25239-3.

6.4.5 A certificate of qualification is to be issued in accordance with ISO 25239-3.

Contents

■ *Section 1*
General welding requirements

1.1 Scope

1.1.1 This Chapter specifies requirements for fabrication and welding during construction and repair of ships or other marine structures, and their associated pressure vessels, machinery, equipment, components and products intended for use in these structures.

1.1.2 The requirements for fabrication and welding during construction and repair of tanks intended for transport or storage of liquefied gases are located in the *Rules and Regulations for the Construction and Classification of Ships for the Carriage of Liquefied Gases in Bulk, July 2016* or the *Rules and Regulations for the Classification of a Floating Offshore installation at a Fixed Location*, as appropriate.

1.1.3 The requirements relate to fusion welding. Special consideration will be given to the use of other welding processes based on these requirements.

1.1.4 It is the responsibility of the manufacturer to ensure compliance with all aspects of these Rules and inform the Surveyor of any deviations that have occurred. All deviations are to be recorded as non-compliances along with the corrective actions taken and failure to do this is considered to render the fabrication to be in non-compliance with the Rules.

1.1.5 Welded constructions that comply with National or International specifications may be accepted to the satisfaction of the surveyor, provided that these specifications give reasonable equivalence to the requirements of this Chapter.

1.1.6 All welded construction is to be to the satisfaction of the Surveyor.

1.2 Design

1.2.1 Prior to commencing any work, the component to be manufactured is to be subjected to design review and approval in accordance with the Rule requirements.

1.2.2 The material characteristics that are affected by welding, particularly the loss of strength (e.g. in precipitation or strain hardened aluminium alloys) are to be considered in the design. The weld joints in such materials are to be arranged such that they are in areas of lower stress.

1.3 Materials

1.3.1 Materials used in welded construction are to be manufactured at works approved by LR. The use of materials from alternative sources will be subject to agreement of the Surveyor and satisfactory verification testing.

1.3.2 Materials are to be supplied and certified in accordance with the requirements of *Ch 1 General Requirements* of these Rules.

1.3.3 Materials used in welded construction are to be readily weldable and are to have proven weldability, unless requirements are agreed with LR in advance.

1.3.4 Where the construction details are such that materials are subject to through thickness strains, consideration is to be given to using material with specified through thickness properties as specified in *Ch 3, 8 Plates with specified through thickness properties*.

1.3.5 When ordering materials for construction, consideration is to be taken of the possible degradation of properties during fabrication or post-weld heat treatment. Where these materials are used, consideration is to be given to additional test requirements being specified to the supplier.

1.3.6 The identity of materials is to be established by way of markings etc, during fabrication, so that traceability to the original manufacturer's certificate is maintained.

1.3.7 Pre-fabrication shop primers may be applied prior to welding, provided that they are of an approved type and have been tested to demonstrate that they have no deleterious effects on the completed weld.

1.3.8 Where it is proposed to weld forgings and/or castings, full details of the joint details, welding procedures and post-weld heat treatments are to be submitted for consideration.

1.4 Requirements for manufacture and workmanship

1.4.1 The welding workshops are to be assessed by the Surveyor for their capability to produce work of the required quality in accordance with the requirements specified for the type of construction, *see Ch 13, 2 Specific requirements for ship hull structure and machinery*.

1.4.2 Where structural components are to be assembled and welded in works sub-contracted by the builder, the Surveyor is to inspect the sub-contractor's works to ensure that compliance with the requirements of this Chapter is achieved.

1.4.3 The manufacturer is to provide a system of regular supervision of all welding, by suitably qualified and experienced personnel.

1.4.4 Welding is to be performed in covered workshops as far as practicable. Where this is not possible, provision is to be made in the welding area to give adequate protection from wind, rain and cold, etc.

1.4.5 Where required, arrangements are to be such as to permit adequate ventilation and access for preheating, and for the satisfactory completion of all welding operations.

1.4.6 The location of welding connections and sequences of welding are to be arranged to minimise distortion and the build up of residual stresses. Welded joints are to be so arranged as to facilitate the use of downhand welding wherever possible.

1.4.7 In the case of repairs to existing structures or components, care is to be exercised when attaching fit-up aids by welding to ensure that the base materials in way of the attachments are of weldable quality.

1.4.8 In order to prevent cross-contamination of different material types, the welding of carbon steel materials is to be in areas segregated from that used for either austenitic or non-ferrous materials, *see Ch 13, 7 Austenitic and duplex stainless steel – Specific requirements*.

1.5 Cutting of materials

1.5.1 Materials may be cut to the required dimensions by thermal means, shearing or machining in accordance with the manufacturing drawings or specifications.

1.5.2 Cold shearing is not to be used on materials in excess of 25 mm thick. Where used, the cut edges that are to remain un-welded are to be cut back by machining or grinding for a minimum distance of 3 mm.

1.5.3 Material, which has been thermally cut, is to be free from excessive oxides, scale and notches.

1.5.4 All cut edges are to be examined to ensure freedom from material and/or cutting defects. Visual examination may be supplemented by other techniques.

1.5.5 Thermal cutting of alloy and high carbon steels may require the application of preheat, and special examination of these cut edges will be required to ensure no cracking. In these cases, the cut edge is to be machined or ground back a distance of at least 2 mm, unless it has been demonstrated that the cutting process has not damaged the material.

1.5.6 Any material damaged in the process of cutting is to be removed by machining, grinding or chipping back to sound metal. Weld repair may only be performed with the agreement of the Surveyor.

1.6 Forming and bending

1.6.1 Plates, pipes, etc. may be formed to the required shape by any process which does not impair the quality of the material.

1.6.2 Where hot forming is employed or during cold forming where the material is subjected to a permanent strain exceeding 10 per cent or formed to a diameter to thickness ratio less than 10, tests are required to be performed to demonstrate that the material properties remain acceptable.

1.6.3 As far as practicable, forming is to be performed by the application of steady continuous loading using a machine designed for that purpose. The use of hammering, in either the hot or cold condition is not to be employed.

1.6.4 Material may be welded prior to forming or bending, provided that it can be demonstrated that the weld mechanical properties are not impaired by the forming operation. All welds subjected to bending are to be inspected on completion to ensure freedom from surface breaking defects.

1.7 Assembly and preparation for welding

1.7.1 Excessive force is not to be used in fairing and closing the work. Where excessive root gaps exist between surfaces or edges to be joined, corrective measures are to be adopted.

1.7.2 Provision is to be made for retaining correct alignment during welding operations in accordance with the approved manufacturing specifications and welding procedures.

1.7.3 Tack welds are to be avoided as far as practicable. When used, tack welds are to be of the same quality as the finished welds, made in accordance with approved welding procedures, and where they are to be retained as part of the finished weld, they are to be clean and free from defects.

1.7.4 Generally, tack welds are not to be applied in lengths of less than 30 mm for mild steel grades and aluminium alloys, and 50 mm for higher tensile steel grades. Smaller tack welds may be accepted for steels, provided that the carbon equivalent of the materials being welded is not greater than 0,36 per cent.

1.7.5 Where deep penetration welding is used (*see Ch 13, 2.4 Construction and workmanship 2.4.6*), welding procedure tests are to demonstrate that the specified degree of penetration is achieved in way of tack welds left in place.

1.7.6 Where temporary bridge pieces or strong-backs are used, they are to be of similar materials to the base materials and welded in accordance with approved welding procedures.

1.7.7 Any fit-up aids and tack welds, where welded to clad materials, are to be attached to the base material and not to the cladding.

1.7.8 Surfaces of all parts to be welded, are to be clean, dry and free from rust, grease, debris and other forms of contamination.

1.7.9 When misalignment of structural members either side of bulkheads, decks etc. exceeds the agreed tolerance, the misaligned item is to be released, realigned and rewelded in accordance with an approved procedure.

1.8 Welding equipment and welding consumables

1.8.1 Welding plant and equipment is to be suitable for the purpose intended and properly maintained, taking into account relevant safety precautions.

1.8.2 Suitable means of measuring the welding parameters (i.e. current, voltage and travel speed) are to be available. Electrical meters are to be properly maintained and have current calibrations.

1.8.3 Welding consumables are to be suitable for the type of joint and grade of material to be welded, and in general, are to be LR Approved in accordance with *Ch 11 Approval of Welding Consumables*.

1.8.4 Special care is to be taken in the distribution, storage and handling of all welding consumables. They are to be kept in heated dry storage areas with a relatively uniform temperature in accordance with the consumable manufacturer's recommendations. Condensation on the metal surface (e.g. wire electrodes and studs) during storage and use is to be avoided.

1.8.5 Prior to use, welding consumables are to be dried and/or baked in accordance with the consumable manufacturer's recommendations.

1.8.6 Satisfactory storage and handling facilities for consumables are to be provided close to working areas and the condition of welding consumables are to be subject to regular inspections.

1.9 Welding procedure and welder qualifications

1.9.1 Welding procedures are to be developed by the manufacturer for all welding, include weld repairs, and are to be capable of achieving the mechanical property requirements and non-destructive examination quality appropriate to the work being undertaken.

1.9.2 Welding procedures are to be established for the welding of all joints and are to be qualified by testing in accordance with *Ch 12 Welding Qualifications*. The welding procedures are to give details of the welding process, type of consumable, joint preparation, welding position and filler metals to be used.

1.9.3 The proposed welding procedures are to be approved by the Surveyor prior to construction.

1.9.4 All welders and welding operators are to be qualified in accordance with the requirements of *Ch 12 Welding Qualifications*. Qualification records to demonstrate that welding personnel have the skills to achieve the required standard of workmanship are to be available to the Surveyor.

1.10 Welding during construction

1.10.1 Materials to be assembled for welding are to be retained in position by suitable means such that the root gaps and alignment are in accordance with the approved manufacturing specifications and welding procedures.

1.10.2 Surfaces of all parts to be welded, are to be clean, dry and reasonably free from rust, scale and grease.

1.10.3 Pre-heat is to be applied, as specified in the approved welding procedure, for a distance of at least 75 mm from the joint preparation edges. The method of application and temperature control are to be such as to maintain the required level throughout the welding operation.

1.10.4 When the ambient temperature is 0°C or less, or where moisture resides on the surfaces to be welded, due care is to be taken to pre-heat the joint to a minimum of 20°C, unless a higher pre-heat temperature is specified.

1.10.5 Where tack welds are to be removed from the root of the weld joint, this is to be carried out such that the surrounding material and joint preparation is not damaged.

1.10.6 The welding arc is to be struck on the parent metal which forms part of the weld joint or on previously deposited weld metal.

1.10.7 Where the welding process used is slag forming (e.g. manual metal arc, submerged arc, etc.) each run of deposit is to be cleaned and free from slag before the next run is applied.

1.10.8 Full penetration welds are to be made from both sides of the joint as far as practicable. Prior to welding the second side, the weld root is to be cleaned, in accordance with the requirements of the approved welding procedure, to ensure freedom from defects. When air-arc gouging is used, care is to be taken to ensure that the ensuing groove is slag and oxide free and has a profile suitable for welding.

1.10.9 Where welding from one side only, care is to be exercised to ensure the root gap is in accordance with the approved welding procedure and the root is properly fused.

1.10.10 Particular care is to be exercised in welding in the vertical position with direction of travel downward (Vd) to avoid welding defects. The use of solid wire gas metal arc (GMAW) process in the vertical down position is to be avoided.

1.10.11 Welding is to proceed systematically with each welded joint being completed in correct sequence without undue interruption.

1.10.12 After welding has been stopped for any reason, care is to be taken in restarting to ensure that the previously deposited weld metal is thoroughly cleaned of slag and debris, and preheat has been re-established.

1.10.13 Care is to be taken to avoid stress concentrations such as sharp corners or abrupt changes of section, and completed welds are to have an even contour, blending smoothly with the base materials. The weld shape and size is to be in accordance with that specified in the approved drawings or specifications.

1.10.14 Welded temporary attachments used to aid construction are to be removed carefully by grinding, cutting or chipping. The surface of the material is to be finished smooth by grinding followed by crack detection.

1.10.15 Where fabricated and welded components require to be machined, all major welding operations are to be completed prior to final machining.

1.10.16 Welding to parts which are subjected to rotating fatigue (e.g. shafts) is not generally permitted.

1.10.17 Welding onto parts that have been hardened for wear resistance or strength (e.g. gear teeth) is not permitted.

1.10.18 Where welding of clad ferritic steel plates is to be undertaken, the clad materials are to be ground back from the prepared edge by at least 10 mm. In general, the ferritic materials are to be welded prior to welding of the cladding material.

1.11 Non-destructive examination of welds

1.11.1 Non-destructive examinations are to be made in accordance with a definitive written procedure prepared and endorsed by a person qualified according to a Nationally Recognised Scheme with a grade equivalent to Level III qualification of ISO 9712, SNT-TC-1A or ASNT Central Certification Program (ACCP). As a minimum, the procedure will identify personnel qualification levels, NDE datum and identification system, extent of testing, methods to be applied with technique sheets, acceptance criteria and reporting requirements. These procedures are to be reviewed by the Surveyor. *See Ch 1, 5 Non-destructive examination*.

1.11.2 Non-destructive examinations are to be undertaken by personnel qualified according to a Nationally Recognised Scheme with a grade equivalent to Level II qualification of ISO 9712, SNT-TC-1A or ASNT Central Certification Program (ACCP). Operators qualified to Level I of the above schemes (or equivalent recognised by LR) may be engaged in testing under the supervision of personnel qualified to Level II or III (or equivalent recognised by LR). Personnel qualifications are to be verified by certification.

1.11.3 Effective arrangements are to be provided by the manufacturer for the inspection of finished welds to ensure that all welding, and where necessary, all post-weld heat treatment, has been satisfactorily completed.

1.11.4 Welds are to be clean and free from paint at the time of visual inspection unless specified otherwise in the following Sections.

1.11.5 The weld surface finish is to ensure accurate and reliable detection of defects. Where the weld surface is irregular or has other features likely to interfere with the interpretation of non-destructive examination, the weld is to be ground or machined.

1.11.6 Prior to inspection, welded temporary attachments and lifting eyes used to aid construction are to be removed carefully by grinding, cutting or chipping or other approved means. The surface of the material is to be finished smooth by grinding followed by crack detection. Any defects caused in the removal process are to be repaired and re-inspected.

1.11.7 For welds in steels with specified yield strength up to 400 N/mm^2, and with carbon equivalent less than or equal to 0,41 per cent, NDE may be performed as soon as the test assembly has cooled to ambient temperature. For other steels, NDE is to be delayed for a period of at least 48 hours after the test assembly has cooled to ambient temperature.

1.11.8 Non-destructive examinations are to be performed in accordance with the requirements of the Rules. Examinations are to be in accordance with agreed written procedures prepared by the manufacturer or ship builder.

1.11.9 The Surveyor may request additional inspections where there is reason to question the quality of workmanship, or where the weld is part of a complicated fabrication where there is high restraint or high residual stresses.

1.11.10 Welds are to be examined after completion of any post-weld heat treatment.

1.11.11 Where weld defects are discovered, the full extent is to be ascertained by applying additional non-destructive examinations where required. Unacceptable defects are to be completely removed and, where necessary, weld repaired in accordance with the relevant Sections of this Chapter. The repairs are to be re-inspected using the same technique as the original inspection.

1.11.12 Results of non-destructive examinations are to be recorded and evaluated by the constructor on a continual basis in order that the quality of welding can be monitored. These records are to be available to the Surveyor.

1.11.13 The constructor is to be responsible for the review, interpretation, evaluation and acceptance of the results of NDE. Reports stating compliance or otherwise with the criteria established in the inspection procedure are to be issued. Reports are to comply, as a minimum, with the requirements of *Ch 1, 5 Non-destructive examination*.

1.11.14 The extent of applied non-destructive examination is to be increased when warranted by the analysis of previous results.

1.11.15 Ultrasonic testing of welds in austenitic and duplex stainless steels requires specific procedures, appropriately qualified personnel and suitable equipment including angle-compression wave and creep wave probes, in addition to the above requirements.

1.12 Routine weld tests

1.12.1 Routine or production weld tests may be specified as a means of monitoring the quality of the welded joints. This type of quality control test is generally specified for pressure vessel and LNG construction but may be used for other types of welded fabrication.

1.12.2 Routine weld tests may be requested by the Surveyor where there is reason to doubt the quality of workmanship.

1.12.3 Where routine weld tests have been agreed, they are to be performed in accordance with the general requirements for the type of construction, *see Ch 13, 3 Specific requirements for fabricated steel sections* and *Ch 13, 4 Specific requirements for fusion welded pressure vessels*.

1.13 Rectification of material defects

1.13.1 Repair of defects found in base materials is not to be carried out without the prior approval of the Surveyor.

1.13.2 In general, surface defects in the material may be removed by grinding, chipping, etc. provided the remaining material thickness is not reduced below the minimum thickness tolerance, and the area is ground to blend in smoothly with the surrounding material.

1.13.3 Confirmation that the defect has been removed is required by performing visual examination, augmented by either magnetic particle or dye penetrant examination techniques.

1.13.4 Surface defects, which cannot be repaired by the above method, may be repaired by welding where permitted by *Ch 3 Rolled Steel Plates, Strip, Sections and Bars*. Such repairs are to be performed in accordance with the requirements of this Section and those specified in *Ch 3 Rolled Steel Plates, Strip, Sections and Bars*.

1.13.5 Any defects in the structure resulting from the removal of temporary attachments are to be prepared, efficiently welded and ground smooth so as to achieve a defect free repair.

1.14 Rectification of distortion

1.14.1 Fairing, by linear or spot heating, to correct distortions due to welding, may be carried out. In order to ensure that the properties of the material are not adversely affected, approved procedures are to be utilised. On completion of such processes, visual examination of all heat affected areas in the vicinity is to be carried out to ensure freedom from cracking.

1.14.2 When misalignment of members exceeds the agreed tolerance, the misaligned item is to be cut apart, realigned and re-welded in accordance with an approved procedure.

1.15 Rectification of welds defects

1.15.1 Where repairs are extensive the manufacturer is to investigate the reason for the defects and take the necessary actions to prevent recurrence. In addition, consideration is to be given to the sequence of repairs and to providing temporary supports to prevent misalignment or collapse.

1.15.2 Cracks are to be reported to the Surveyor and the cause established prior to undertaking weld repairs.

1.15.3 Defects may be removed by grinding, chipping or thermal gouging. Where thermal gouging is used, the repair groove is to be subsequently ground clean to remove oxides and debris. The groove is to have a profile suitable for welding.

1.15.4 Prior to commencing repair welding, it is to be confirmed that no defect exists on the prepared surface by performing visual examination, augmented by either magnetic particle or dye penetrant examination techniques.

1.15.5 Repair welding is to be performed using approved welding procedures.

1.15.6 Completed repairs are to be re-examined by the non-destructive examination method(s) that detected the original defect and are to confirm that the original defect has been removed.

1.15.7 Where the component or structure has been subjected to post-weld heat treatment prior to weld repair, this is to be repeated after completion of all repair welding.

1.15.8 Where non-destructive examination reveals that the original defect has not been successfully removed, one more repair attempt may be performed.

1.15.9 The manufacturer is to monitor the quality of welding and maintain records of welding repairs and take the necessary corrective actions where repair rates are outside normal limits.

1.16 Post-weld heat treatment

1.16.1 On completion of welding, post-weld heat treatment may be required depending on the type of welded construction, the material type and thickness as specified by the relevant Parts or Sections of the Rules.

1.16.2 In general, heat treatment after welding is to be a stress relief treatment in order to reduce residual stresses introduced by welding and is generally applicable to ferritic steels. Where other types of heat treatment (e.g. normalising, solution annealing) are proposed, demonstration of acceptable mechanical properties of the weldment are to be confirmed by a welding procedure test which includes a simulated heat treatment.

1.16.3 Parts are to be properly prepared for heat treatment. Machined surfaces (e.g. flange faces, screw threads, etc.) are to be protected against scaling and sufficient temporary supports provided to prevent distortion or collapse of the structure.

1.16.4 Details of the heat treatment to be applied, soaking time and temperature, heating and cooling rates, etc. are to be submitted for review prior to commencing.

1.16.5 Post-weld heat treatment is to be carried out in a purpose built furnace which is efficiently maintained. In special cases, where the configuration of the component is such that thermal stresses during heating and cooling can be minimised, local post-weld heat treatment may be used. This would not normally apply to the complex geometry of cast materials during manufacture within the foundry environment.

1.16.6 In all cases, the heat treatment facilities and arrangements are to be capable of controlling the temperature throughout the heat treatment cycle and adequate means of measuring and recording the component temperature are to be provided. Thermocouples are to be attached so they are in contact with the component.

1.16.7 Unless specified otherwise, stress relief heat treatment is to be carried out by means of controlled heating from 300°C, to the soak temperature, holding within the prescribed soaking temperature range for the time specified (usually 1 hour per 25 mm of weld thickness) followed by controlled cooling to below 300°C.

1.16.8 Where post-weld stress relief is specified for welded constructions that contain joints between different materials (e.g. ferritic to austenitic steels), the details of the materials, welding procedures and heat treatment cycle to be applied are to be submitted for special consideration and approval.

1.16.9 Non-destructive examination of welds is to be performed after completion of any heat treatment.

1.17 Certification

1.17.1 Products or components are not to be considered complete until all the requirements of the construction specification have been met and all activities have been completed.

1.17.2 Upon completion of the works, the manufacturer is to provide documentation which indicates that:

(a) All welds are complete and there are no outstanding repairs.
(b) The appropriate post-weld heat treatments have been performed.
(c) Appropriate destructive tests have been performed.
(d) Proof testing of welds has been performed.

1.17.3 Before the test certificates or shipping statements are signed by the Surveyor, the manufacturer is required to provide a written declaration stating that the product is in accordance with the requirements of *Ch 13, 1.17 Certification 1.17.2*.

■ *Section 2*
Specific requirements for ship hull structure and machinery

2.1 Scope

2.1.1 The requirements of this Section apply to the construction of ships, including hull structure, superstructure and deckhouses, components forming part of the ship structure and its machinery (excluding pressure equipment and piping, *see Ch 13, 4 Specific requirements for fusion welded pressure vessels*). These requirements are in addition to the general welding requirements specified in *Ch 13, 1 General welding requirements*.

2.1.2 The shipyard and manufacturer's works are to be assessed to give assurance that they have the facilities, equipment, personnel and quality control procedures to produce work of the required quality.

2.2 Welding consumables

2.2.1 Welding consumables used for hull construction are to be approved in accordance with *Ch 11 Approval of Welding Consumables* and are to be suitable for the type of joint and grade of material to be welded.

2.2.2 Steel welding consumable approvals, up to and including Grade Y40, and Y47, are considered acceptable for hull construction in line with *Table 11.1.1 Welding consumable grades appropriate to structural and low temperature service steel grades* in Chapter 11, *Ch 12, 2.2 Welding variables 2.2.2* and the following:

(a) Consumables up to Grade Y are acceptable for welding steels up to 3 strength levels below that for which the approval applies, e.g. a consumable with approval grading 3Y is acceptable for welding EH36, EH32 and EH27S higher tensile ship steels and grade E normal strength ship steel.
(b) Consumables for Grade Y40 are acceptable for welding steels up to two strength levels below that for which the approval applies. Consumables for Grade Y47 are acceptable for welding steels up to one strength level below that for which the approval applies.
(c) Consumables with an approved impact toughness grading are acceptable for welding steels with lower specified impact properties subject to (a) above, e.g. a consumable with approval grading 3Y is acceptable for welding EH, DH and AH materials.
(d) For welding steels of different grades or different strength levels, the welding consumables may be of a type suitable for the lesser grade or strength being connected. The use of a higher grade of welding consumable may be required at discontinuities or other points of stress concentration.

2.2.3 In general, the use of preheating and hydrogen controlled welding consumables for welding of ship steels up to strength grade H40 is to be in accordance with *Table 13.2.1 Preheat and consumable requirements for welding of carbon and carbon manganese steels up to strength grade H40*. The carbon equivalent is to be calculated from the ladle analysis using the formula given below:

$$\text{Carbon equivalent} = \mathbf{C} + \frac{\mathbf{Mn}}{\mathbf{6}} + \frac{\mathbf{Cr + Mo + V}}{\mathbf{5}} + \frac{\mathbf{NI + Cu}}{\mathbf{15}}$$

Preheat and the use of low hydrogen controlled consumables will be required for welding of steel grades higher than Grade H40.

Table 13.2.1 Preheat and consumable requirements for welding of carbon and carbon manganese steels up to strength grade H40

Carbon equivalent C_{eq}	Preheat	Hydrogen controlled consumables
C_{eq} equal to or less than 0,41%	Not required	Not required, *see* Note 3
C_{eq} above 0,41 but not exceeding 0,45%	Not required, *see* Notes 1 and 2	Required
C_{eq} greater than 0,45%	Required	Required

Note 1. Preheat may need to be applied in order to meet the maximum hardness values specified in *Ch 12, 2.12 Mechanical test acceptance criteria for steels 2.12.6*.

Note 2. Under conditions of high restraint or low ambient temperature preheat may need to be applied.

Note 3. Hydrogen controlled consumables may need to be considered for welding of (a) Thicker materials (i.e. > 35 mm). (b) Higher strength materials. (c) Welds subject to high restraint.

2.2.4 All aluminium alloy welding consumables are to be approved in accordance with *Ch 11 Approval of Welding Consumables* and are suitable for welding the grades of material as shown in *Table 13.2.2 Welding of aluminium alloys - Consumable requirements*.

Table 13.2.2 Welding of aluminium alloys - Consumable requirements

Consumable approval grade	Base material alloy grade
RA or WA	5754
RB or WB	5086, 5754
RC or WC	5083, 5086, 5754
RD or WD	6005A, 6061, 6082

2.2.5 All austenitic stainless steel and duplex stainless steel welding consumables are to be approved in accordance with the *Ch 11 Approval of Welding Consumables* and are suitable for welding the grades of material as shown in *Table 13.2.3 Welding of austenitic stainless and duplex stainless steels - Consumable requirements*.

Table 13.2.3 Welding of austenitic stainless and duplex stainless steels - Consumable requirements

Consumable approval grade	Suitable for welding material alloy grades
Austenitic stainless steels	
321	321
347	347 and 321
Austenitic stainless steel – Low carbon	
304L (*see* Note 3)	304L
304LN (*see* Note 3)	304LN and 304L
316L	316L and 304L
316LN	316LN, 316L, 304LN and 304L
317L	317L, 316LN, 316L, 304LN and 304L
317LN	317LN, 317L, 316LN, 316L, 304LN and 304L
Super austenitic stainless steels, *see* Note 2	
S31254	S31254 and N08904
N08904	N08904
Duplex stainless steels, *see* Note 1	
S31260	S31260 and S31803
S31803	S31803
S32550	S32550
S32750	S32750 and S32550
S32760	S32760, S32550, S31260 and S31803
Stainless steels welded to carbon steels	
SS/CMn	Carbon steel to all steels in Sections 1, 2 and 3
Duplex/CMn	Carbon steel to all duplex stainless steel in Section 4
Note 1. The use of a different welding consumable grade from that of the base material may require demonstration of acceptable corrosion properties. Note 2. May be used for welding low carbon austenitic grades provided measures are taken to prevent solidification cracking from occurring. Note 3. These are LR Grades and do not correspond to any National or International Standards/Grades.	

2.3 Welding procedure and welder qualifications

2.3.1 Welding procedures and welder qualifications are to be tested and approved in accordance with the requirements of *Ch 12 Welding Qualifications*.

2.4 Construction and workmanship

2.4.1 Weld preparations and openings may be formed by thermal cutting, machining or chipping. Chipped surfaces that will not be subsequently covered by weld metal are to be ground smooth.

2.4.2 Prior to welding, the alignment of plates and stiffeners forming part of the hull structure is to be in accordance with the tolerances specified in the relevant part of the Rules.

2.4.3 When welding from one side only, care is to be exercised to ensure the root gap and fit up are in accordance with the approved welding procedure and the root is properly fused.

2.4.4 Where it is proposed to use permanent backing strips, the intended locations and welding procedures are to be submitted for consideration.

2.4.5 Temporary backing strips may be used provided they are in accordance with approved welding procedures and are subsequently removed on completion of welding.

2.4.6 The outer surfaces of completed welds are to blend smoothly with the base materials and provide a smooth transition and gradual change of section.

2.4.7 Weld joints in parts of oil engine structures that are stressed by the main gas or inertia loads are to be designed as continuous full penetration welds. They are to be arranged so that welds do not intersect, and that welding can be effected without difficulty.

2.4.8 When modifications or repairs have been made which result in openings having to be closed by welded inserts, particular care is to be given to the fit of the insert and the welding sequence. The welding is also to be subject to non-destructive examination.

2.4.9 Where welding of aluminium alloy is employed, the following additional requirements are to be complied with so far as they are applicable:

(a) Welding is to be performed by fusion welding using inert gas or tungsten inert gas process or by the friction stir welding process. Where it is proposed to use other welding processes, details are to be submitted for approval.
(b) The weld joint surfaces should be scratch brushed, preferably immediately before welding, in order to remove oxide or adhering films of dirt, filings, etc.

2.5 Butt welds

2.5.1 Where the ship hull is constructed of plates of different thicknesses, the thicker plates are to be chamfered in accordance with the approved plans. In all cases the chamfer is not to exceed a slope of 1 in 3 so that the plates are of equal thickness at the weld seam. Alternatively, if so desired, the width of the weld may be included as part of the smooth taper to the thicker plate provided the difference in thickness is not greater than 3 mm.

2.5.2 Where stiffening members are attached by continuous fillet welds and cross completely finished butt or seam welds, these are to be made flush in way of the fillet weld. Similarly for butt welds in webs of stiffening members, the butt weld is to be complete and generally made flush with the stiffening member before the fillet weld is made. Where these conditions cannot be complied with, a scallop is to be arranged in the web of the stiffening member, *see Figure 13.2.1 Weld dimensions and types*. Scallops are to be of such a size and in such a position that a satisfactory weld can be made.

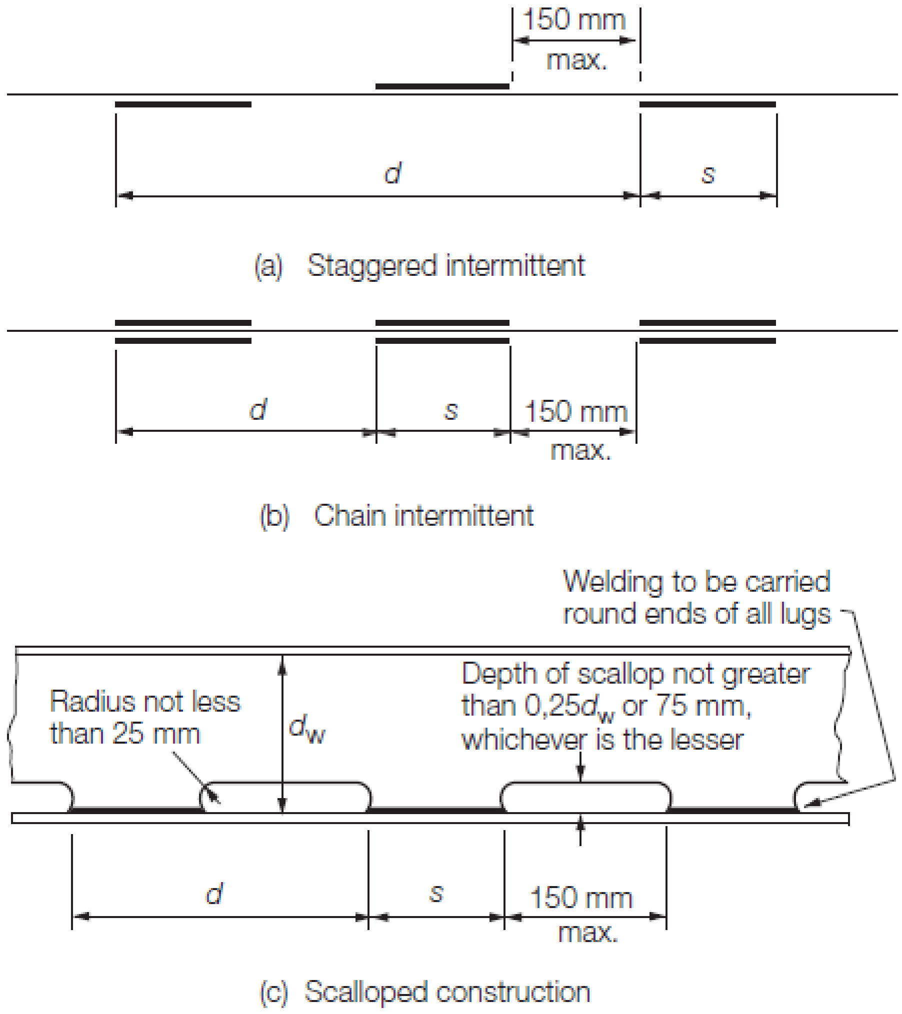


Figure 13.2.1 Weld dimensions and types

2.6 Lap connections

2.6.1 Overlaps are generally not to be used to connect plates which may be subjected to high tensile or compressive loading and alternative arrangements are to be considered. However, where plate overlaps are adopted, the width of the overlap is not to exceed four times, nor be less than three times the thickness of the thinner plate and the joints are to be positioned to allow adequate access for completion of sound welds. The faying surfaces of lap joints are to be in close contact and both edges of the overlap are to have continuous fillet welds.

2.7 Closing plates

2.7.1 For the connection of plating to internal webs, where access for welding is not practicable, the closing plating is to be attached by continuous full penetration welds or by slot fillet welds to face plates fitted to the webs. Slots are to have a minimum length of 90 mm and a minimum width of twice the plating thickness, with well rounded ends. Slots cut in plating are to be smooth and clean and are to be spaced not more than 230 mm apart, centre to centre. Slots are not to be filled with welding.

2.7.2 For the attachment of rudder shell plating to the internal stiffening of the rudder, slots are to have a minimum length of 75 mm and, in general, a minimum width of twice the side plating thickness. The ends of the slots are to be rounded and the space between them is not to exceed 150 mm.

2.8 Stud welding

2.8.1 Where permanent or temporary studs are to be attached by welding to main structural parts in areas subject to high stress, the proposed location of the studs and the welding procedures adopted are to be approved.

2.9 Fillet welds

2.9.1 T-connections are generally to be made by fillet welds on both sides of the abutting plate, the dimensions and spacing of which are shown in *Figure 13.2.1 Weld dimensions and types*. Where the connection is highly stressed, deep penetration or full penetration welding may be required. Where full penetration welding is required, the abutting plate may be required to be bevelled.

2.9.2 Where an approved deep penetration procedure is used, the fillet leg length calculated may be reduced by 15 per cent provided that the manufacturer is able to meet the following requirements:

(a) Use of a welding consumable approved for deep penetration welding in accordance with *Ch 11 Approval of Welding Consumables* for either the ‘p’ or ‘T’ techniques.
(b) Demonstrations by way of production weld testing that the minimum required penetration depths (i.e. throat thicknesses) are maintained. This is to be documented on a monthly basis by the manufacturer and be available to the Surveyor.

2.9.3 The calculated fillet leg length may be reduced by 20 per cent, provided that in addition to the requirements of *Ch 13, 2.9 Fillet welds 2.9.2* and *Ch 13, 2.9 Fillet welds 2.9.2*, the manufacturer is able to consistently meet the following additional requirements:

(a) The documentation required in *Ch 13, 2.9 Fillet welds 2.9.2* is to be completed and made available to the Surveyor upon request on a weekly basis.
(b) Suitable process selection confirmed by satisfactory welding procedure tests covering both minimum and maximum root gaps.

2.9.4 Where intermittent welding is used, the welding is to be made continuous in way of brackets, lugs and scallops and at orthogonal connections with other members.

2.10 Post-weld heat treatment

2.10.1 Post-weld stress relief heat treatment is applied to improve the fatigue performance or to improve resistance to brittle fracture and is generally required for carbon and carbon-manganese and low alloy steels under any of the following conditions:

(a) Where the material thickness exceeds 65 mm.
(b) For complicated weld joints where there are high stress concentrations.
(c) Where fatigue loads are considered high.

2.10.2 Post-weld heat treatment is to be applied to the following types of welded construction:

(a) Welding of steel castings where the thickness of the casting at the weld exceeds 30 mm, except where castings are directly welded to the hull structure.
(b) Engine bedplates except engine types where the bedplate as a whole is not subjected to direct loading from the cylinder pressure. For these types, only the transverse girder assemblies need to be stress relieved.
(c) Welding of gear wheels.
(d) Welding of gear cases associated with main or auxiliary engines, *see Pt 5 Main and Auxiliary Machinery*.

2.10.3 Where required, heat treatment is to be performed in accordance with the requirements specified in *Ch 13, 4.10 Post-weld heat treatment* for pressure vessel construction.

2.10.4 Special consideration may be given to omit the required post-weld heat treatment. Evaluation is to be based on critical engineering assessment involving fracture mechanics testing and proposals are to be submitted which include full details of the application, materials, welding procedures, inspection procedures, design stresses, fatigue loads and cycles. Evidence will be required to demonstrate that the inspection techniques and procedures to be employed are able to detect flaws down to the sizes determined from the fracture mechanics (and or fatigue) calculations. Alternative procedures for omission of post weld heat treatment will be subject to special consideration.

2.11 Tolerances

2.11.1 Tolerances after welding are to be in accordance with the relevant Part of the Rules.

2.11.2 Distortion which has resulted from welding may be corrected by spot heating in accordance with *Ch 13, 1.14 Rectification of distortion*.

2.12 Non-destructive examination of welds

2.12.1 All finished welds are to be sound and free from cracks and substantially free from lack of fusion, incomplete penetration, porosity and slag. The surfaces of welds are to be reasonably smooth and substantially free from undercut and overlap. Care is to be taken to ensure that the specified dimensions of welds have been achieved and that both excessive reinforcement and under-fill of welds is avoided.

2.12.2 Welds forming part of the hull and superstructure may be coated with a thin layer of protective primer prior to inspection provided it does not interfere with inspection and is removed, if required by the Surveyor, for closer interpretation of possible defective areas.

2.12.3 All welds are to be visually inspected by personnel designated by the builder. Visual inspection of all welds may be supplemented by other non-destructive examination techniques in cases of unclear interpretation, as considered necessary. The acceptance criteria for visual testing are given in *Table 13.2.4 Acceptance criteria for visual testing, magnetic particle and liquid penetrant testing*.

Table 13.2.4 Acceptance criteria for visual testing, magnetic particle and liquid penetrant testing

Surface discontinuity	Classification according to ISO 6520-1	Acceptance criteria for visual testing
Crack	100	Not accepted
Lack of fusion	401	Not accepted
Incomplete root penetration in butt joints welded from one side	4021	Not accepted
Surface pore	2017	Single pore diameter $d \leq 0{,}25t$, for butt welds, with maximum diameter 3 mm, *see* Note 1 $d \leq 0{,}25a$, for fillet welds, with maximum diameter 3 mm, *see* Note 1 2,5d as minimum distance to adjacent pore
Undercut in butt welds	501	Depth ≤ 0,5 mm, whatever the length Depth ≤ 0,8 mm, with a maximum continuous length of 90 mm, *see* Note 2
Undercut in fillet welds	501	Depth ≤ 0,8 mm, whatever the length
Note 1. *t* is the plate thickness of the thinnest plate, and a is the throat of the fillet weld. Note 2. Adjacent undercuts separated by a distance shorter than the shortest undercut are to be regarded as a single continuous undercut.		

2.12.4 In addition to visual inspection, welded joints are to be examined using any one or a combination of ultrasonic, radiographic, magnetic particle, eddy current, dye penetrant or other acceptable methods appropriate to the configuration of the weld.

2.12.5 The method to be used for the volumetric examinations of welds is the responsibility of the builder. Radiography is generally preferred for the examination of butt welds of 8 mm thickness or less. Ultrasonic testing is acceptable for welds of 8 mm thickness or greater and is to be used for the examination of full penetration tee butt or cruciform welds or joints of similar configuration. Advanced ultrasonic techniques, such as Phased Array Ultrasonic Testing (PAUT), may be used as a volumetric testing method in lieu of radiography or manual ultrasonic testing. If these methods are used, the thickness limitations for manual ultrasonic testing apply.

2.12.6 The acceptance criteria for radiographic testing are given in *Table 13.2.5 Acceptance criteria for radiographic testing*, and those for ultrasonic testing in *Table 13.2.6 Acceptance criteria for ultrasonic testing*.

Table 13.2.5 Acceptance criteria for radiographic testing

Discontinuity	Classification according to ISO 6520-1	Acceptance criteria for radiographic testing, *see* Note 1
Crack	100	Not accepted
Lack of fusion	401	Continuous maximum length $t/2$ or 25 mm, whichever is the less, *see* Note 2 Intermittent cumulative length maximum t or 50 mm, whichever is less, *see* Note 3
Lack of root fusion	4013	Not accepted in butt joints welded from one side
Incomplete root penetration	4021	Not accepted in butt joint welded from one side
		Continuous maximum length $t/2$ or 25 mm, whichever is lesser, *see* Note 2 Intermittent cumulative maximum length t or 50 mm, whichever is less, *see* Note 3
Slag inclusion	301	Continuous maximum length t or 50 mm, whichever is less, *see* Note 2 Intermittent cumulative length maximum $2t$ or 100 mm, whichever is less, *see* Notes 3 and 4
Gas pore	2011	maximum dimension for a single pore: $d \leq 0{,}2t$, max. 4,0 mm *see* Note 5
Uniformly distributed porosity	2012	Maximum dimension of the area of imperfections: For single run welds: $\leq$ 1,5% For multi-run welds: $\leq$ 3% *see* Notes 6 and 7
Clustered (localised) porosity	2013	Maximum dimension of the summation of the projected area of the imperfection: $\leq$ 8% *see* Notes 6 and 7
Elongated cavity	2015	$h \leq 0{,}3t$, max. 3,0 mm $l \leq t$, max. 50 mm *see* Notes 8 and 9
Wormholes	2016	$h \leq 0{,}3t$, max. 3,0 mm $l \leq t$, max. 50 mm *see* Notes 8 and 9
Metallic inclusions other than copper	304	$h \leq 0{,}3t$, max. 3,0 mm *see* Note 8

Copper inclusions	3042	Not permitted

Note 1. t is the thickness of the thinnest plate.

Note 2. Two adjacent individual discontinuities of length l_d 1 and l_d 2 situated on a line and where the distance l_d between them is shorter than the shortest discontinuity are to be regarded as a continuous discontinuity of length l_d 1+l_d+l_d 2

Note 3. Sum of the length of individual continuous discontinuities.

Note 4. Parallel inclusions not separated by more than 3 times the width of the largest inclusion are to be regarded as one continuous discontinuity.

Note 5. d is the diameter of the gas pore.

Note 6. The limits for the maximum single gas pore within this group still apply.

Note 7. Further reference to porosity limits may be obtained in ISO 5817:2007.

Note 8. h is the width of the imperfection.

Note 9. l is the length of the imperfection.

Table 13.2.6 Acceptance criteria for ultrasonic testing

Echo height	Acceptance criteria for ultrasonic testing, *see* Note
Greater than 100% of DAC curve	Maximum length t/2 or 25 mm, whichever is less
Greater than 50% of DAC curve, but less than 100% of DAC curve	Maximum length t or 50 mm, whichever is less
Indications evaluated to be cracks are unacceptable regardless of echo height; Indications evaluated to be lack of penetration or lack of root fusion in joints welded from one side are unacceptable regardless of echo height.	
Note Two adjacent individual discontinuities of length L1 and L2 situated on a line and where the distance L between them is shorter than the shortest discontinuity are to be regarded as a continuous discontinuity of length L1 + L + L2.	

2.12.7 Checkpoints examined at the pre-assembly stage are to include ultrasonic testing on examples of the stop/start points of automatic welding and magnetic particle inspection of weld ends.

2.12.8 Checkpoints examined at the assembly stage are generally to be selected from those welds intended to be examined as part of the agreed quality control programme to be applied by the builder. The locations and number of checkpoints are to be approved by the Surveyor.

2.12.9 Where components of the structure are subcontracted for fabrication, the same inspection regime is to be applied as if the item had been constructed within the main contractor's works. In these cases, particular attention is to be given to highly loaded fabrications (such as stabiliser fin boxes) forming an integral part of the hull envelope.

2.12.10 Particular attention is to be paid to highly stressed items. Magnetic particle inspection is to be used at ends of fillet welds, T-joints, joints or crossings in main structural members and at stern frame connections.

2.12.11 Special attention is to be given to the examination of plating in way of lifting eye plate positions to ensure freedom from cracks. This examination is not restricted to the positions where eye plates have been removed, but includes the positions where lifting eye plates are permanent fixtures.

2.12.12 Checkpoints for volumetric examination are to be selected so that a representative sample of welding is examined.

2.12.13 Typical locations for volumetric examination and number of checkpoints to be taken are given in the relevant Sections of the Rules. A list of the proposed items to be examined is to be submitted for approval.

2.12.14 For the hull structure of refrigerated spaces, and of ships designed to operate in low air temperatures, the extent of non-destructive examination will be specially considered. For non-destructive examination of gas ships see the *Rules for the carriage for Liquefied Gases*.

2.12.15 For all ship types, the builder is to carry out random non-destructive examination at the request of the Surveyor.

2.12.16 Results of non-destructive examinations made during construction are to be recorded and evaluated by the builder on a continual basis in order that the quality of welding can be monitored. These records are to be available to the Surveyor.

2.12.17 The extent of applied non-destructive examinations is to be increased when warranted by the analysis of previous results.

2.13 Weld repairs

2.13.1 The full extent of any weld defect is to be ascertained by applying additional non-destructive examination where required. Unacceptable defects are to be completely removed and, where necessary, re-welded and re-examined in accordance with the requirements of *Ch 13, 1.15 Rectification of welds defects*.

2.13.2 During the assembly of large components, root gaps in excess of those specified in the approved welding procedure may be rectified by welding.

2.13.3 Rectification of wide root gaps in butt welds, up to a maximum gap of 16 mm, may be performed provided that the length of these areas is small in relation to the whole weld length. Repairs may be executed by applying weld buttering layers to one edge of the weld joint, followed by machining or grinding to return the root opening to the required dimensions. The weld buttering and filling of the joint are to be in accordance with welding procedures qualified in accordance with *Ch 12 Welding Qualifications*.

2.13.4 For sub-assemblies, rectification of wide root gaps may be performed using a backing strip, provided that it is removed on completion of the welding.

2.13.5 Rectification of wide root gaps in fillet welds may be carried out as follows:

(a) where the root gap, g, is in excess of 3 mm, but not greater than 5 mm, the fillet leg length, z, may be increased by g – 2,0 mm;
(b) where the root gap is in excess of 5 mm, the joint detail may be changed into a full penetration weld.

2.13.6 Where repair welds are made using small weld beads, suitable precautions (including preheat) are to be taken to avoid high hardness and possible cold cracking.

2.14 Welding afloat with water backing

2.14.1 Welding afloat with water backing is not recommended due to the additional precautions required during survey and therefore, is generally not permitted. However consideration may be given to welding afloat with water backing after specific LR approval has been obtained by the yard or fabricator prior to such welding being carried out. Such approval will only be given once all of the following conditions are satisfied:

(a) The welding procedure qualification tests are carried out on steel plates with water backing and the water is maintained at the flow rate and minimum water temperature anticipated during fabrication.
(b) The carbon equivalent of the steel plates used in the welding procedure qualification tests are to be greater than 0,41 per cent based on the IIW formula. Where it can be shown that all hull steel plates and new sections will have a carbon equivalent value below this figure, steel plates with the maximum carbon equivalent value may be used for the welding procedure qualification tests.
(c) Welding procedure qualification tests are carried out without preheat.
(d) The thickness of steel plate used in the welding procedure qualification test is the minimum hull plate thickness to be used during fabrication.
(e) The maximum measured hardness on the completed welding procedure qualification assembly is less than or equal to 350 HV10. Following fabrication welding, 10 per cent of welds are to be hardness tested in way of heataffected zones at weld starts to confirm compliance with the 350 HV10 limit.
(f) The heat input used in the welding qualification test is the minimum permitted heat input during fabrication.
(g) Only low hydrogen welding consumables (H5) are used.
(h) In addition to normal non-destructive testing for welds, 10 per cent of the welds are additionally subject to magnetic particle inspection 48 hours after welding is complete.
(i) The welding procedure qualification tests for the repair of welds carried out afloat with water backing are to be carried out on test pieces that have previously been welded afloat and also meet the requirements above.

2.14.2 For new construction, conversion or permanent repairs, wet underwater welding is not permitted.

Section 3
Specific requirements for fabricated steel sections

3.1 Scope

3.1.1 Fabricated steel sections are items used in place of rolled sections and as such will not be regarded as subassemblies. Products regarded as sub-assemblies are subject to requirements of welded construction specified in *Ch 13, 2 Specific requirements for ship hull structure and machinery*.

3.1.2 The requirements for structural steel sections are based on these being manufactured from flat products by automatic welding and intended for use in the construction of ships and other marine structures.

3.1.3 Fabricated steel sections are to be manufactured in accordance with the requirements of this Section and the general requirements of *Ch 13, 1 General welding requirements*.

3.1.4 In all cases, sections are to be manufactured at works, which have been assessed and approved in accordance with *Materials and Qualification Procedures for Ships, Book J, MQPS Procedure 12-1*.

3.2 Dimensions and tolerances

3.2.1 Products are to conform dimensionally to the provisions of an acceptable National or International Standard.

3.2.2 The minimum throat thickness of fillet welds is to be determined from:

Throat thickness = 0,34t but not to be taken as less than 3 mm

where

t = plate thickness of the thinner member to be joined (generally the web).

3.2.3 Where a welding procedure using deep penetration welding is used (*see Ch 11 Approval of Welding Consumables*, ‘p’ and ‘T’ welding techniques) the minimum leg length required will be specially considered provided the requirements of *Ch 13, 2.9 Fillet welds 2.9.2* are complied with.

3.2.4 Unless agreed otherwise, the leg length of the weld is to be not less than 1,4 times the specified throat thickness.

3.3 Identification of products

3.3.1 Every finished item is to be clearly marked by the manufacturer in at least one place with the following particulars:

(a) The manufacturer’s name or trade mark.
(b) Identification mark for the grade of steel.
(c) Identification number and/or initials which will enable the full history of the item to be traced.
(d) Where required by the purchaser, the order number or other identification mark.
(e) The letters ‘LR'.
(f) The Surveyor’s personal stamp.

The above particulars, but excluding the manufacturer’s name or trade mark where this is embossed on finished products, are to be encircled with paint or otherwise marked so as to be easily recognisable.

3.3.2 In the event of any material bearing LR’s brand failing to comply with the test requirements, the brand is to be removed or unmistakably defaced, *see also Ch 1, 4.7 Rectification of defective material*.

3.4 Manufacture and workmanship

3.4.1 For cut edges that are to remain unwelded, it is to be demonstrated that the plate preparation procedures used are able to achieve edges that are free from cracks or other deleterious imperfections.

3.4.2 Where assembly jigs and devices are used to bring the web into contact with the flanges and hold these in place during welding, means are to be provided to ensure that the degree of contact is maintained until welding is complete.

3.4.3 Welding procedures are to be established for the welding of all joints including weld repairs and are to be approved in accordance with *Ch 12 Welding Qualifications*. Welders are to be approved in accordance with *Ch 12 Welding Qualifications*, and qualification records are to be available to the Surveyor.

3.4.4 The welding consumables used are to be approved in accordance with *Ch 11 Approval of Welding Consumables* and are to be suitable for the type of joint and grade of steel as described in *Ch 13, 2.2 Welding consumables*. For joining steel of different tensile strengths, the consumables are to be suitable for the tensile strength of the component considered in the determination of weld size.

3.4.5 The application of pre-heat and the use of low hydrogen welding consumables are to be in accordance with the requirements of *Ch 13, 2.2 Welding consumables*.

3.4.6 Welding is to be double continuous fillet welding or full penetration welding as specified in the approved plans.

3.4.7 Where deep penetration welding is used, the requirements of *Ch 13, 2.9 Fillet welds 2.9.2* are to be complied with.

3.5 Non-destructive examination

3.5.1 Surface inspection and verification of dimensions are the responsibility of the manufacturer and are to be carried out on all materials prior to despatch. Acceptance by the Surveyor of material later found to be defective does not absolve the manufacturer from this responsibility.

3.5.2 The Surveyor will carry out checks to ensure that the weld size and profile are in accordance with the manufacturing specification and the manufacturer's Quality Control Procedures.

3.5.3 The manufacturer is to examine the welds by magnetic particle or dye penetrant methods. The length examined is to be 200 mm at each end, for each length cut for delivery.

3.5.4 If cracks are revealed, these are to be reported to the Surveyor and the whole of the length is to be examined by magnetic particle or dye penetrant methods. Corrective action in respect of the manufacturing process, and repairs are to be as indicated in the manufacturers' Quality Control Manual.

3.5.5 The weld defect is not to exceed the acceptance levels given in *Table 13.2.4 Acceptance criteria for visual testing, magnetic particle and liquid penetrant testing*.

3.6 Routine weld tests

3.6.1 One production batch test is required for every 500 m of fabricated section manufactured, or fraction thereof. From each batch test, two samples are to be removed, one from near the beginning of the production run and one from near the end. From each of these test samples one macro specimen and one fracture test specimen are to be taken.

3.6.2 The macro specimens are to be prepared and etched to demonstrate freedom from unacceptable defects and that the weld penetration is in accordance with the manufacturing specification. The fracture specimens are to be broken, one for each side of the fillet welds and the fractured surfaces examined for compliance with the requirements of *Table 13.2.5 Acceptance criteria for radiographic testing*.

3.6.3 Where the welding procedure used has employed the deep penetration technique, the amount of root penetration is to be measured on the macro specimen and is not to be less than that demonstrated during welding procedure approval testing.

3.6.4 For the purposes of this Section, a batch is to consist of products of only one size and grade of material.

3.7 Certification and records

3.7.1 Each test certificate is to include the following particulars:

(a) Purchaser's name and order number.
(b) Where known, the contract number for which the material is intended.
(c) Address to which material is despatched.
(d) Description and dimensions of the product.
(e) Specification or grade of the steel.
(f) Identification number and/or initials.
(g) Cast number and chemical composition of ladle samples of constituent plates.
(h) Mechanical test results of constituent plates.
(i) Condition of supply when other than as-rolled.
(j) Make and brand of welding consumables.

3.7.2 Test certificates or shipping statements may be signed by the Surveyor, provided the documentation requirements of *Ch 13, 1.17 Certification* are satisfied. The following form of declaration will be accepted if stamped or printed on each test certificate or shipping statement with the name of the works and signed by an authorised representative of the manufacturer: 'We hereby

certify that the material has been made by an approved procedure in accordance with the *Rules for the Manufacture, Testing and Certification of Materials, July 2016*'.

3.7.3 The manufacturer is to maintain records by which sources of material can be identified together with the results of all inspections and tests.

■ *Section 4*
Specific requirements for fusion welded pressure vessels

4.1 Scope

4.1.1 The requirements of this Section apply to fusion welded pressure vessels and process equipment, heating and steam raising boilers, and steam or gas turbine rotors and cylinders and are in addition to those requirements referred to in *Ch 13, 1 General welding requirements*.

4.1.2 The allocation of pressure vessel Class is determined from the design criteria in *Pt 5, Ch 10 Steam Raising Plant and Associated Pressure Vessels* and *Pt 5, Ch 11 Other Pressure Vessels* of the *Rules and Regulations for the Classification of Ships, July 2016*. Prior to commencing construction, the design of the vessel is to be approved. Construction requirements for turbine rotors and cylinders are to be in accordance with Class 2/1, unless a higher Class is specified in the approved plans.

4.1.3 Pressure vessels will be accepted only if manufactured by firms equipped and competent to undertake the quality of welding work required for the Class of vessel proposed. The manufacturer's works are to be approved in accordance with the requirements specified in *Materials and Qualification Procedures for Ships, Book A, Procedure MQPS 0-4*.

4.1.4 The term 'fusion weld', for the purpose of these requirements, is applicable to welded joints made by manual, semi-automatic, or automatic electric arc welding processes. Special consideration will be given to the proposed use of other fusion welding processes.

4.2 Cutting and forming of shells and heads

4.2.1 Cut or chipped surfaces which will not be subsequently covered by weld metal are to be ground smooth.

4.2.2 Shell plates and heads are to be formed to the correct contour up to the extreme edge of the plate.

4.2.3 Vessels manufactured from carbon or carbon manganese steel plates (*see Table 3.4.1 Chemical composition and deoxidation practice* in *Ch 3 Rolled Steel Plates, Strip, Sections and Bars*, grades 360AR to 510FG), which have been hot formed or locally heated for forming, are to be re-heat treated in accordance with the original supplied condition on completion of this operation. Vessels formed from plates supplied in the as-rolled condition are to be heat treated in accordance with the material manufacturer's recommendations.

4.2.4 Subsequent heat treatment will not be required where steels are supplied in the as-rolled, normalised or normalised and controlled rolled condition, or hot forming is carried out entirely at a temperature within the normalising range.

4.2.5 For alloy steel vessels where hot forming is employed (*see Table 3.4.1 Chemical composition and deoxidation practice* in *Ch 3 Rolled Steel Plates, Strip, Sections and Bars*, 13Cr Mo 45 etc.), the plates are to be heat treated on completion in accordance with the material manufacturer's recommendations.

Table 13.4.1 Impact test requirements

Pressure vessel Class	Minimum design temperature	Plate material thickness t	Impact test temperature
Class 1 *see* Note	–10°C or above	All	5°C below the minimum design temperature or 20°C, whichever is the lower
All Classes	Below –10°C	$t \leq 20$ mm	5°C below the minimum design temperature
		20 mm < $t \leq 40$ mm	10°C below the minimum design temperature

		Over 40 mm	Subject to special consideration
Note Impact testing is not required for Classes 2/1, 2/2 and 3.			

4.2.6 Where plates are cold formed, subsequent heat treatment is to be performed where the internal radius is less than 10 times the plate thickness. For carbon and carbonmanganese steels this heat treatment may be a stress relief heat treatment.

4.2.7 In all cases where hot forming is employed, and for cold forming to a radius less than 10 times the thickness, the manufacturer is required to demonstrate that the forming process and subsequent heat treatments result in acceptable properties.

4.3 Fitting of shell plates and attachments

4.3.1 The location of welded joints is to be such as to avoid intersecting butt welds in the vessel shell plates. The attachment of nozzles and openings in the vessels are to be arranged to avoid main shell weld seams.

4.3.2 The surfaces of the plates at the longitudinal or circumferential seams are not to be out of alignment with each other, at any point, by more than 10 per cent of the plate thickness. In no case is the misalignment to exceed 3 mm for longitudinal seams, or 4 mm for circumferential seams.

4.3.3 Where a vessel is constructed of plates of different thicknesses (tube plate and wrapper plate), the plates are to be so arranged that their centrelines form a continuous circle.

4.3.4 For longitudinal seams, the thicker plate is to be equally chamfered inside and outside by machining over a circumferential distance not less than twice the difference in thickness, so that the plates are of equal thickness at the longitudinal weld seam. For the circumferential seam, the thickest plate is to be similarly prepared over the same distance longitudinally.

4.3.5 For the circumferential seam, where the difference in the thickness is the same throughout the circumference, the thicker plate is to be reduced in thickness by machining to a taper for a distance not less than four times the offset, so that the two plates are of equal thickness at the weld joint. A parallel portion may be provided between the end of the taper and the weld edge preparation; alternatively, if so desired, the width of the weld may be included as part of the smooth taper to the thicker plate.

4.3.6 All attachments (lugs, brackets, reinforcing plates, etc.) are to conform to the shape of the surface to which they are attached.

4.4 Welding

4.4.1 Welding procedures are to be established for all welds joining pressure containing parts and for welds made directly onto pressure containing parts. Welding procedures are to be based on qualification tests performed in accordance with *Ch 12 Welding Qualifications*.

4.4.2 In all cases where tack welds, in the root of the weld seam, are used to retain plates or parts in position prior to welding, they are to be removed in the process of welding the seam.

4.4.3 Steel backing strips may be used for the circumferential seams of Class 2/1, Class 2/2 and Class 3 pressure vessels and are to be the same nominal composition as the plates to be welded.

4.4.4 Fillet welds are to be made to ensure proper fusion and penetration at the root of the fillet. At least two layers of weld metal are to be deposited at each weld affixing branch pipes, flanges and seatings.

4.4.5 The outer surface of completed welds is to be at least flush with the surface of the plates joined, and any weld reinforcement is to provide a smooth transition and gradual change of section with the plate surface.

4.4.6 Where attachment of lugs, brackets, branches, manhole frames, reinforcement plates and other members are to be made to the main pressure shell by welding, this is to be to the same standard as required for the main vessel shell construction.

4.4.7 The main weld seams and all welded attachments made to pressure containing parts are to be completed prior to post weld heat treatment.

4.4.8 The finish of welds attaching pressure parts and non-pressure parts to the main pressure shell is to be such as to allow satisfactory examination of the welds. In the case of Class 1 and Class 2/1 pressure vessels, these welds are to be ground smooth, if necessary, to provide a suitable finish for examination.

4.5 General requirements for routine weld production tests

4.5.1 Routine weld production tests are specified as a means of monitoring the quality of the welded joints and are required for pressure vessel Classes 1, 2/1 and 2/2.

4.5.2 Routine production test plates are required during the manufacture of vessels and as part of the initial approval test programme for Class 1 vessel manufacturers, refer to *MQPS 0-4*.

4.5.3 Routine production weld tests are not required for Class 3 pressure vessels unless there are doubts about the weld quality where check tests may be requested by the Surveyor.

4.5.4 Routine production test plates are not required for circumferential seams of cylindrical pressure vessels. Spherical vessels are to have one test plate prepared having a welded joint which is a simulation of the circumferential seams.

4.5.5 Routine production weld tests may be requested by the Surveyor where there is reason to doubt the quality of workmanship.

4.6 Production test plate assembly requirements

4.6.1 Two test plates and one complete test assembly, of sufficient dimensions to provide all the required mechanical test specimens is to be prepared for each vessel and is to be welded as a continuation and simulation of the longitudinal weld joint.

4.6.2 For Class 2/2 vessels, where a large number are made concurrently at the same works using the same welding procedure and the plate thicknesses do not vary by more than 5 mm, one test may be performed for each 37 m of longitudinal plus circumferential weld seam. In these cases the thickness of the test plate is to be equal to the thickest shell plate used in the construction.

4.6.3 Where the vessel size or design results in a small number of longitudinal weld seams, one test assembly may be prepared for testing provided that the welding details are the same for each seam.

4.6.4 Test plate materials are to be the same grade, thickness and supply condition and from the same cast as that of the vessel shell. The test assembly is to be welded at the same time as the vessel weld to which it relates and is to be supported so that distortion during welding is minimised.

4.6.5 As far as practicable, welding is to be performed by different welders where there is a requirement for several routine tests to be welded.

4.6.6 The test assembly may be detached from the vessel weld only after the Surveyor has performed a visual examination and has added his mark or stamp. Straightening of test welds prior to mechanical testing is not permitted.

4.6.7 Where the pressure vessel is required to be subjected to post-weld heat treatment, the test weld is to be heat treated, after welding, in accordance with the same requirements. This may be performed separately from the vessel.

4.7 Inspection and testing

4.7.1 The test weld is to be subjected to the same type of non-destructive examination and acceptance criteria as specified for the weld seam to which the test relates. Nondestructive examination is to be performed prior to removing specimens for mechanical testing, but after any post-weld heat treatment.

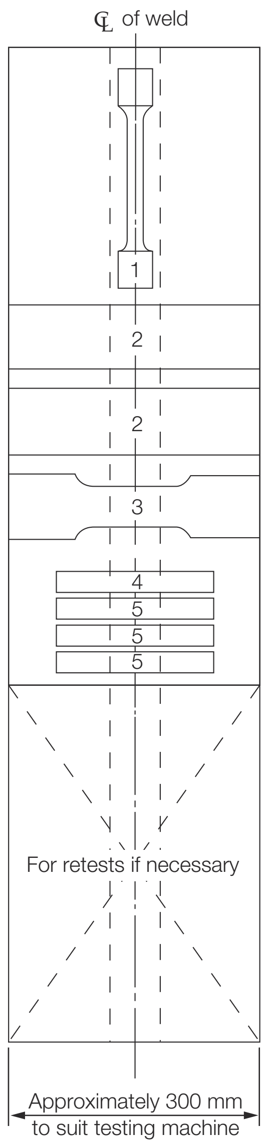
4.7.2 The test weld is to be sectioned to remove the number and type of test specimens for mechanical testing as given in 4.8.

4.8 Mechanical requirements

4.8.1 The routine production test assembly is to be machined to provide the following test specimens:

(a) Tensile.
(b) Bend.
(c) Hardness.
(d) Impact (*see Table 13.4.1 Impact test requirements*).
(e) Macrograph and hardness survey of full weld section.

4.8.2 One set of specimens for mechanical testing are to be removed, as shown in *Figure 13.4.1 Routine weld test - Test specimens for Class 1 and Class 2/1* or *Figure 13.4.2 Routine weld tests - Test specimens for Class 2/2 and Class 3* as appropriate for the Class of approval. Impact tests are to be removed and tested where required by *Table 13.4.1 Impact test requirements*.



1. All weld metal tensile test specimen.
2. Bend test specimens.
3. Tensile test for joints.
4. Macro-test specimen.
5. Charpy V-notch impact.
(For all Class 1 pressure vessels and other Classes of pressure vessels where the minimum design temperature is below –10°C).

Figure 13.4.1 Routine weld test - Test specimens for Class 1 and Class 2/1

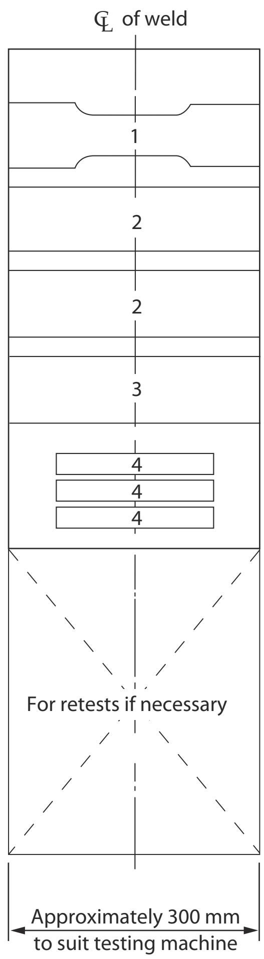


Figure 13.4.2 Routine weld tests - Test specimens for Class 2/2 and Class 3

Note 1. Tensile test for joints.

Note 2. Bend test specimens.

Note 3. Nicked bend test specimen.

Note 4. Charpy V-notch impact test specimens (if required by *Ch 13, 4.2 Cutting and forming of shells and heads 4.2.5*).

4.8.3 **Longitudinal tensile test for weld metal.** An all-weld metal longitudinal tensile test is required. For thicknesses in excess of 20 mm, where more than one welding process or type of consumable has been used to complete the joint, additional longitudinal tests are required from the respective area of the weld. This does not apply to the welding process or consumables used solely to deposit the root weld. Specimens are to be tested in accordance with the following requirements:

(a) The diameter and gauge length of the test specimen is to be in accordance with *Ch 11, 2.1 Dimensions of test specimens 2.1.1*.

(b) For carbon and carbon-manganese steels the tensile strength of the weld metal is to be not less than the minimum specified for the plate material and not more than 145 N/mm^2 above this value. The percentage elongation, *A*, is to be not less than that given by:

$A = (980\text{-}R)/21{,}6$ but not less than 80 per cent of the minimum elongation specified for the plate

where

= *R* is the tensile strength, in N/mm^2, obtained from the all weld metal tensile tests.

(a) For other materials the tensile strength and percentage elongation is not to be less than that specified for the base materials welded.

4.8.4 **Transverse tensile test for joint.** Transverse tensile test specimens are to be removed and tested in accordance with the following requirements:

(a) One reduced section tensile test specimen is to be cut transversely to the weld to the dimensions shown in *Ch 11, 2.1 Dimensions of test specimens 2.1.1* and the weld reinforcement is to be removed.
(b) In general, where the plate thickness exceeds 30 mm, or where the capacity of the tensile test machine prevents full thickness tests, each tensile test may be made up of several reduced section specimens, provided that the whole thickness of the weld is subjected to testing.
(c) The tensile strength obtained is to be not less than the minimum specified tensile strength for the plate material, and the location of the fracture is to be reported.

4.8.5 **Transverse bend test.** The bend test specimens are to be removed and tested in accordance with the following requirements:

(a) Two bend test specimens of rectangular section are to be cut transversely to the weld, one bent with the outer surface of the weld in tension (face bend), and the other with the inner surface in tension (root bend).
(b) The specimen dimensions are to be in accordance with *Ch 2 Testing Procedures for Metallic Materials*.
(c) Each specimen is to be mounted on roller supports with the centre of the weld midway between the supports. The former is to have a diameter specified in *Ch 12, 2.7 Destructive tests for steel butt welds 2.7.6* depending on the material being welded.
(d) After bending through an angle of at least 180° there is to be no crack or defect exceeding 1,5 mm measured across the specimen or 3 mm measured along the specimen. Premature failure at the edges of the specimen is not to be cause for rejection, unless this is associated with a weld defect.

4.8.6 **Macro-specimen and hardness survey.** A macro examination specimen is to be removed from the test assembly near the end where welding started. The specimen is to include the complete cross-section of the weld and the heat affected zone. The specimen is to be prepared and examined in accordance with the following requirements:

(a) The cross-section of the specimen is to be ground, polished and etched to clearly reveal the weld runs, and the heat affected zones.
(b) The specimen is to show an even weld profile that blends smoothly with the base material and have satisfactory penetration and fusion, and an absence of significant inclusions or other defects.
(c) Where there is doubt in the condition of the weld as shown by macro-etching, the area concerned is to be microscopically examined.
(d) For carbon, carbon manganese and low alloy steels, a Vickers hardness survey is to be performed on the macro-specimen using either a 5 kg or 10 kg load. Testing is to include the base material, the weld and the heat affected zone. Hardness scans on the crosssection are to be performed as specified in *Figure 12.2.14 Hardness testing locations for butt welds* in Chapter 12. The maximum recorded hardness is to not exceed 350 Hv.

4.8.7 **Charpy V-notch impact test.** Charpy V notch impact test specimens are to be prepared and tested as required by *Table 13.4.1 Impact test requirements* and in accordance with the following requirements:

(a) The dimensions and tolerances of the specimens are to be in accordance with *Ch 2 Testing Procedures for Metallic Materials*.
(b) Charpy V-notch impact specimens and are to be removed with the notch perpendicular to the plate surface.
(c) Specimens are to be removed for testing from the weld centreline and the heat affected zone (fusion line and fusion line + 2 mm locations) detailed in *Figure 12.2.11 Locations of V-notch for butt weld of normal heat input (heat input ≤ 50 kJ/cm)* or *Figure 12.2.12 Locations of V-notch for butt weld of high heat input (heat input > 50 kJ/cm)* in Chapter 12, as appropriate. Heat affected zone impact tests may be omitted where the minimum design temperature is above +20°C.
(d) For thicknesses in excess of 20 mm, where more than one welding process or type of consumable has been used to complete the joint, impact tests are required from the respective areas of the weld. This does not apply to the welding process or consumables used solely to deposit the root weld.
(e) The average energy of a set of three specimens is not to be less than 27 J or the minimum specified for the base material, whichever is the higher. The minimum energy for each individual specimen is to meet the requirements of *Ch 1, 4.5 Mechanical tests 4.5.2*.

4.8.8 **Nick break bend tests.** A nick bend or fracture test specimen is to be a minimum of 100 mm long measured along the weld direction and is to be tested in accordance with and meet the requirements of the following:

(a) The specimen is to have a slot cut into each side along the centreline of the weld and perpendicular to the plate surface.
(b) The specimen is to be bent along the weld centreline until fracture occurs and the fracture faces are to be examined for defects. The weld is to be sound, with no evidence of cracking or lack of fusion or penetration and be substantially free from slag inclusions and porosity.

4.9 Failure to meet requirements

4.9.1 Where any test specimen fails to meet the requirements, additional specimens may be removed and re-tested in accordance with *Ch 2, 1.4 Re-testing procedures*.

4.9.2 Where a routine weld test fails to meet requirements, the welds to which it relates will be considered as not having met the requirements. The reason for the failure is to be established, and the manufacturer is to take such steps as necessary to either

(a) Remove the affected welds and have them re-welded, or
(b) Demonstrate that the affected production welds have acceptable properties.

4.10 Post-weld heat treatment

4.10.1 Fusion welded pressure vessels, where indicated in *Table 13.4.2 Post-weld heat treatment requirements*, are to be heat treated on completion of the welding of the seams and of all attachments to the shell and ends, and before the hydraulic test is carried out.

Table 13.4.2 Post-weld heat treatment requirements

Type of steel	Plate thickness above which post-weld heat treatment (PWHT) is required	
	Steam raising plant	Other pressure vessels
Carbon and carbon/ manganese steels without low temperature impact values	20 mm	30 mm
Carbon and carbon/ manganese steels with low temperature impact values	20 mm	40 mm
1Cr ½Mo	All thicknesses	All thicknesses
2¼Cr 1Mo	All thicknesses	All thicknesses
½Cr ½Mo ¼V	All thicknesses	All thicknesses
Other alloy steels	Subject to special consideration	

4.10.2 Tubes which have been expanded into headers or drums may be seal welded without further post-weld heat treatment.

4.10.3 Steam and gas turbine cylinders and rotors are to be subjected to post-weld heat treatment irrespective of thickness.

4.10.4 Where the weld attaches parts of different thicknesses, the thickness to be used when applying the requirements for post-weld heat treatment is to be either the thinner of the two plates for butt welded connections, or the thickness of the shell for welds to flanges, tubeplates and similar connections.

4.10.5 Care is to be exercised to provide drilled holes in double reinforcing plates and other closed spaces prior to heat treatment.

4.11 Basic requirements for post-weld heat treatment of fusion welded pressure vessels

4.11.1 Recommended soaking temperatures and soak durations for post-weld heat treatment are given in *Table 13.4.3 Post-weld soak temperatures and times* for different materials. Where other materials are used for pressure vessel construction, full details of the proposed heat treatment are to be submitted for consideration.

Table 13.4.3 Post-weld soak temperatures and times

Material type	Soak temperature (°C)	Soak period
Carbon and carbon/ manganese grades	580–620°	1 hour per 25 mm of thickness, minimum 1 hour
1Cr ½Mo	620–660°	1 hour per 25 mm of thickness, minimum of 1 hour
2¼Cr 1Mo	650–690°	1 hour per 25 mm of thickness, minimum of 1 hour
½Cr ½Mo ¼V	670–720°	1 hour per 25 mm of thickness, minimum of 1 hour
Note For materials supplied in the tempered condition, the post-weld heat treatment temperature is to be lower than the material tempering temperature.		

4.11.2 Where pressure vessels are of dimensions that the whole length cannot be accommodated in the furnace at one time, the pressure vessels may be heated in sections, provided that sufficient overlap is allowed to ensure the heat treatment of the entire length of the longitudinal seam.

4.11.3 Where materials other than those detailed in *Table 13.4.3 Post-weld soak temperatures and times* are used or where it is proposed to adopt special methods of heat treatment, full particulars are to be submitted for consideration. In such cases, it may be necessary to carry out tests to show the effect of the proposed heat treatment.

4.12 Non-Destructive Examination of welds

4.12.1 Non-Destructive Examinations (NDE) of pressure vessel welds are to be carried out in accordance with a nationally recognised code or standard.

4.12.2 NDE is not to be applied until an interval of at least 48 hours has elapsed since the completion of welding.

4.12.3 NDE Personnel are to be qualified to an appropriate level of a nationally recognised certification scheme.

4.12.4 Qualification schemes are to include assessments of practical ability for Levels I and II individuals. These examinations are to be made on representative test pieces containing relevant defects.

4.13 Extent of NDE for Class 1 pressure vessels

4.13.1 All butt welded seams in drums, shells, headers and test plates, together with tubes or nozzles with outside diameter greater than 170 mm, are subject to 100 per cent volumetric and surface crack detection inspections.

4.13.2 For circumferential butt welds in extruded connections, tubes, headers and other tubular parts with an outside diameter of 170 mm or less, at least 10 per cent of the total number of welds is to be subjected to volumetric examination and surface crack detection inspections.

4.13.3 Full penetration tube sheet to shell welds are to be subjected to 10 per cent volumetric examination and 10 per cent surface inspection, prior to the installation of the tubes.

4.13.4 In addition to the acceptance limits stated in *Table 13.2.4 Acceptance criteria for visual testing, magnetic particle and liquid penetrant testing*, no cracks, lack of fusion, or lack of penetration is permitted.

4.13.5 When an unacceptable indication is detected, the full length of the weld is to be subjected to 100 per cent examination by the same method, testing conditions and acceptance criteria.

4.13.6 The NDE requirements of *Ch 13, 1.11 Non-destructive examination of welds* are to be complied with.

4.14 Extent of NDE for Class 2/1 pressure vessels

4.14.1 For Class 2/1 pressure vessels, volumetric and surface crack detection inspections are to be applied at selected regions of each main seam. At least 10 per cent of each main seam is to be examined together with the full length of each welded test plate. When an unacceptable indication is detected, at least two additional check points in the seam are to be selected by the surveyor for examination using the same inspection method. Where further unacceptable defects are found either:

(a) the whole length of weld represented is to be cut out and re-welded and re-examined as if it was a new weld with the test plates being similarly treated, or
(b) the whole length of the weld represented is to be reexamined using the same inspection methods.

4.14.2 Butt welds in furnaces, combustion chambers and other pressure parts for fired pressure vessels under external pressure, are to be subject to spot volumetric examination. The minimum length for each check point is to be 300 mm.

4.14.3 The extent of NDE for turbine cylinders and rotors is to be agreed with the Surveyor.

4.14.4 The requirements of *Ch 13, 4.13 Extent of NDE for Class 1 pressure vessels 4.13.3*, *Ch 13, 4.13 Extent of NDE for Class 1 pressure vessels 4.13.4* and *Ch 13, 4.13 Extent of NDE for Class 1 pressure vessels 4.13.5* apply to Class 2/1 pressure vessels.

4.15 NDE Method

4.15.1 Volumetric examinations may be made by radiography. For welds of nominal thickness greater than or equal to 8 mm, the examinations may be by ultrasonic testing. The preferred method for surface crack detection in ferrous metals is magnetic particle inspection. The preferred method for nonmagnetic materials is liquid penetrant inspection.

4.16 Evaluation and reports

4.16.1 The manufacturer is to be responsible for the review, interpretation, evaluation and acceptance of the results of NDE. Reports stating compliance, or non-compliance, with the criteria established in the inspection procedure are to be issued. Reports are to comply, as a minimum, with the requirements of *Ch 1, 5 Non-destructive examination*.

4.17 Repair to welds

4.17.1 Where non-destructive examinations reveal unacceptable defects in the welded seams, they are to be repaired in accordance with *Ch 13, 1.15 Rectification of welds defects* and are to be shown by further non-destructive examinations to have been eliminated.

4.17.2 In the case where spot radiography has revealed unacceptable defects, the requirements of *Ch 13, 4.14 Extent of NDE for Class 2/1 pressure vessels 4.14.1* apply.

4.17.3 Where post-weld heat treatment is required in accordance with *Ch 13, 4.10 Post-weld heat treatment*, weld repairs to the vessel or cylindrical shell or parts attaching to the shell are to be subjected to a subsequent heat treatment in accordance with *Ch 13, 4.10 Post-weld heat treatment*.

4.17.4 In the event of unsuccessful weld repair of a defect, only one more repair attempt may be made of the same defect. Any subsequent repairs may require the re-repair excavation to be enlarged to remove the original repair heat affected zone.

■ *Section 5*
Specific requirements for pressure piping

5.1 Scope

5.1.1 Fabrication of piping is to be carried out in accordance with the requirements of this Section and the general requirements given in *Ch 13, 1 General welding requirements*, unless more stringent requirements have been specified.

5.1.2 Piping systems are to be constructed in accordance with the approved plans and specifications.

5.1.3 Fabricated piping will be accepted only if manufactured by firms that have demonstrated that they have the facilities and equipment and are competent to undertake the quality of welding required for the Class of pipework proposed.

5.2 Manufacture and workmanship

5.2.1 Pipe welding may be performed using manual, semi-automatic or fully automatic electric arc processes. The use of oxy-acetylene welding will be limited to Class 3 piping in carbon steel or carbon/manganese material that is not for carrying flammable fluids and limited to butt joints in pipes not exceeding 100 mm diameter or 9,5 mm thickness.

5.2.2 Welding of piping, including attachment welds directly to pressure retaining parts is to be performed in accordance with approved welding procedures that have been qualified in accordance with *Ch 12 Welding Qualifications*.

5.2.3 Where the work involves a significant number of branch connections, tests will be required to demonstrate that the type of joint(s) and welding techniques employed are capable of achieving the required quality.

5.2.4 Where pressure piping is assembled and butt welded in situ, the piping is to be arranged well clear of adjacent structures to allow sufficient access for preheating, welding, heat-treatment and non-destructive examination of the joints.

5.2.5 Alignment of pipe butt welds is to be in accordance with *Table 13.5.1 Pipe butt weld alignment tolerances* unless more stringent requirements have been agreed. Where fusible inserts are used, the alignment is to be within 0,5 mm in all cases.

Table 13.5.1 Pipe butt weld alignment tolerances

Pipe size	Maximum permitted misalignment
D < 150 mm and $t \le 6$ mm	1,0 mm or 25% of t, whichever is the lesser
D < 300 mm and $t \le 9,5$ mm	1,5 mm or 25% of t, whichever is the lesser
$D \ge 300$ and $t > 9,5$ mm	2,0 mm or 25% of t, whichever is the lesser
where D = pipe internal diameter t = pipe wall thickness	

5.2.6 The number of welds is to be kept to a minimum. The minimum separation between welds, measured toe-to-toe, is to be not be less than 75 mm. Where it is not possible to achieve this, adjacent welds are to be subjected to surface crack detection NDE.

5.2.7 Welding consumables and fusible root inserts, where used, are to be suitable for the materials being joined.

5.2.8 Acceptable methods of flange attachment are to be used, *see Figure 12.2.2 Typical welded-on flanges* in *Pt 5, Ch 12 Piping Design Requirements*of the Rules for Ships. Where backing rings are used with flange type (a) they are to fit closely to the bore of the pipe and be removed after welding. The rings are to be made of the same material as the pipes. The use of flange types (b) and (c) with alloy steel pipes is limited to pipes up to and including 168,3 mm outside diameter.

5.2.9 Where socket welded fittings are employed, the diametrical clearance between the outside diameter of the pipe and the base of the fitting is not to exceed 0,8 mm, and a gap of approximately 1,5 mm is to be provided between the end of the pipe and the internal step at the bottom of the socket.

5.2.10 For welding of carbon, carbon/manganese and low alloy steels, the preheat to be applied will be dependent on the material grade, thickness and hydrogen grading of the welding consumable in accordance with *Table 13.5.2 Welding preheat levels for piping*, unless welding procedure testing indicates that a higher level is required.

Table 13.5.2 Welding preheat levels for piping

Material Grade	Thickness,t (mm) *see* Note 4	Minimum preheat temperature (°C) *See* Note 1	
		Non-low H_2	Low H_2 *see* Note 2
Carbon and carbon/ manganese grades:	$t \le 15$	50	10
320 and 360	$t \ge 15$	100	50
Carbon and carbon/ manganese grades:	$t \le 15$	75	20
410, 460 and 490	$t \ge 15$	150	100

1Cr ½Mo	$t < 13$ $t \geq 13$	*See* Note 3	100 150
2¼Cr 1Mo	$t < 13$ $t \geq 13$	*See* Note 3	150 200
½Cr ½Mo ¼V	$t < 13$ $t \geq 13$	*See* Note 3	150 200

Note 1. Where the ambient temperature is 0°C or below, pre-warming of the weld joint is required in all cases.

Note 2. Low hydrogen process or consumables are those that have been tested and have achieved a grading of H15 or better (*see Ch 11 Approval of Welding Consumables*).

Note 3. Low hydrogen welding process is required for these materials.

Note 4. t = the thickness of the thinner member for butt welds, and the thicker member for fillet and branch welds.

5.2.11 Welding without filler metal is generally not permitted for welding of duplex stainless steel materials.

5.2.12 All welds in high pressure, high temperature pipelines are to have a smooth surface finish and even contour; and where necessary, made smooth by grinding.

5.2.13 Check tests of the quality of the welding are to be carried out periodically.

5.3 Heat treatment after bending of pipes

5.3.1 After forming or bending of pipes, the heat treatments specified in this Section are to be applied unless the pipe material manufacturer specifies or recommends other requirements.

5.3.2 Generally, hot forming is to be carried out within the normalising temperature range. When carried out within this temperature range, no subsequent heat treatment is required for carbon and carbon/manganese steels. For alloy steels, 1Cr ½Mo, 2¼Cr 1Mo and ½Cr ½Mo ¼V, a subsequent tempering heat treatment in accordance with the temperatures and times specified in *Table 13.5.3 Heat treatment after bending of pipes* is required, irrespective of material thickness.

Table 13.5.3 Heat treatment after bending of pipes

Type of steel	Heat treatment required
Carbon and carbon/ manganese: Grades 320, 360, 410, 460 and 490	Normalise at 880 to 940°C
1Cr ½Mo	Normalise at 900 to 940°C, followed by tempering at 640 to 720°C
2¼Cr 1Mo	Normalise at 900 to 960°C, followed by tempering at 650 to 780°C
½Cr ½Mo ¼V	Normalise at 930 to 980°C, followed by tempering at 670 to 720°C
Other alloy steels	Subject to special consideration

5.3.3 When hot forming is performed outside the normalising temperature range, a subsequent heat treatment in accordance with *Table 13.5.3 Heat treatment after bending of pipes* is required.

5.3.4 After cold forming to a radius (measured at the centreline of the pipe) of less than four times the outside diameter, heat treatment in accordance with *Table 13.5.3 Heat treatment after bending of pipes* is required.

5.3.5 Heat treatment should be carried out in accordance with *Ch 13, 1.16 Post-weld heat treatment*.

5.3.6 Bending procedures and subsequent heat treatment for other alloy steels will be subject to special consideration.

5.4 Post-weld heat treatment

5.4.1 Post-weld heat treatment is to be carried out in accordance with the general requirements specified in *Ch 13, 1.16 Post-weld heat treatment* and *Ch 13, 4.10 Post-weld heat treatment*.

5.4.2 The thickness limits, the recommended soaking temperatures and periods, for application of post-weld heat treatment are given in *Table 13.5.4 Post-weld heat treatment requirements for piping*.

Table 13.5.4 Post-weld heat treatment requirements for piping

Material Grade	Thickness for which post-weld heat treatment is required	Soak temperature (°C) *see* Note 2	Soak period
Carbon and carbon/ manganese grades: 320, 360, 410, 460, 490	Over 30 mm	580–620°C	1 hour per 25 mm of thickness, 320, 360, 410, 460, 490 minimum of 1 hour
1Cr ½Mo	Over 8 mm	620–660°C	1 hour per 25 mm of thickness, minimum of 1 hour
2¼Cr 1Mo	All	650–690°C	1 hour per 25 mm of thickness, minimum of 1 hour
½Cr ½Mo ¼V	All, *see* Note 1	670–720°C	1 hour per 25 mm of thickness, minimum of 1 hour
Note 1. Heat treatment may be omitted for thicknesses up to 8 mm and diameters not exceeding 100 mm provided welding procedure tests have demonstrated acceptable properties in the as welded condition. Note 2. For materials supplied in the tempered condition, the post weld heat treatment temperature is to be at least 20°C less than the material tempering temperature.			

5.4.3 Where the use of oxy-acetylene welding is proposed, due consideration is to be given to the need for normalising and tempering after such welding.

5.5 Non-destructive examination

5.5.1 Non-destructive examination of pipe welds is to be carried out in accordance with the general requirements of *Ch 13, 1.11 Non-destructive examination of welds* and the following.

5.5.2 Butt welds in Class 1 pipes with an outside diameter greater or equal to 75 mm are to be subject to 100 per cent volumetric and visual inspections. Consideration is to be given to the extent and method of testing applied to butt welds in Class 1 pipes with an outside diameter less than 75 mm.

5.5.3 Butt welds in Class II pipes are to be subjected to at least 10 per cent random volumetric inspections when the outside diameter is greater than 100 mm.

5.5.4 NDE for Class II pipes with a diameter less than 100 mm is to be at the discretion of the Surveyor.

5.5.5 Non-destructive examination procedures, methods and the evaluation of reports are to be in accordance with *Ch 13, 4.15 NDE Method* and *Ch 13, 4.16 Evaluation and reports*.

5.5.6 Fillet welds on flange pipe connections of Class I pipes are to be examined by surface crack detection methods.

5.5.7 Weld acceptance criteria shall be in accordance with *Ch 13, 4.13 Extent of NDE for Class 1 pressure vessels*.

5.6 Repairs to pipe welds

5.6.1 Where non-destructive examinations reveal unacceptable defects in a weld, the defects are to be removed and repaired in accordance with *Ch 13, 1.1 Scope*. Completed repairs are to be shown by further non-destructive examination to have eliminated the defects.

5.6.2 For pipes with diameter less than 88 mm and where unacceptable defects have been found during nondestructive examination, consideration is to be given to cutting the weld out completely, re-making the weld preparation and re-welding as a new joint (because of the difficulty of making small repairs).

5.6.3 Where repeated weld repairs have to be made to a weld, only two such attempts are to be permitted, thereafter the weld is to be cut apart and removed, and re-welded as a new joint.

5.6.4 Where piping requires post-weld heat treatment weld, repairs to the pressure retaining parts are to be subjected to a subsequent heat treatment. Similarly, where welding is conducted after pressure testing, a further pressure test is to be required unless specific exemption has been agreed.

■ *Section 6*
Repair of existing ships by welding

6.1 Scope

6.1.1 This Section specifies requirements for repairs made by welding after introduction into service. This Section includes defects to hull structures, machinery, equipment and components. It also includes replacement of structure due to damage or corrosion. These requirements are in addition to those specified in the preceding Sections of this Chapter.

6.1.2 These requirements apply unless the original builder or manufacturer has specified alternative requirements.

6.2 Materials used for repairs

6.2.1 Permanent materials used in the repair are to be in accordance with *Ch 13, 1.3 Materials*.

6.2.2 Prior to commencing any welding, the material grades present in the original structure in way of the repair are to be determined. Where the materials cannot be identified from the ship records, test samples may be removed for chemical analysis and mechanical testing in order to determine the material grades.

6.2.3 Temporary materials that are to be welded to the main structure to assist in executing the repairs, but removed on completion, are to be of weldable quality.

6.3 Workmanship

6.3.1 A repair method is to be established by the shipyard or repair yard and is to be agreed by the Surveyor prior to commencing any repair work.

6.3.2 The removal of crack-like defects is to be confirmed by visual examination and surface crack detection NDE. This may be augmented by ultrasonic examination where several defects are reported at different depths at the same location.

6.3.3 The weld joint or groove shape used for the repair is to have a profile suitable for welding.

6.3.4 The weld area is to be carefully cleaned, in particular, where the material surface has been painted or has been subjected to an oily or greasy environment.

6.4 Non-destructive examination

6.4.1 On completion of welding and any post-weld heat treatment, repair welds are to be subjected to the type and extent of NDE and assessed in accordance with the acceptance criteria specified for the original construction.

6.4.2 Where the original construction specification did not specify NDE, the completed welds are to be, as a minimum, subject to visual examination. Consideration of other NDE techniques is to take due cognisance of the location or the repair within the vessel.

6.4.3 Where spot NDE is applied and defects are found, the extent of NDE is to be increased to include an equal amount of weld length. Where this reveals unacceptable defects, either the whole weld will be rejected or the extent of inspection increased to 100 per cent examination.

6.4.4 The acceptance criteria to be applied are to generally be in accordance with the original build specification. Where conflict of requirements exist, the NDE acceptance limits for welding procedure tests specified in *Ch 12, 2.5 Non-destructive examination (NDE) 2.5.5* may be used as a minimum requirement.

6.5 Repairs to welds defects

6.5.1 Where NDE reveals unacceptable defects, these are to be repaired in accordance with *Ch 13, 1.15 Rectification of welds defects*.

■ *Section 7*
Austenitic and duplex stainless steel – Specific requirements

7.1 Scope

7.1.1 This Section specifies requirements for the fabrication and welding of austenitic and duplex stainless steels, and is in addition to those detailed above.

7.1.2 Fabrication and welding of these materials is to be in designated areas which are separated from those used for other materials, such as carbon steels and copper alloys. Where work is performed in the same workshop as other materials, adequate barriers or screening are to be provided to prevent cross-contamination of different material types.

7.1.3 All tools and equipment used are to be suitable for use on stainless steel materials. The use of tools or equipment made of carbon steel materials is to be avoided. It is permissible to use carbon steel tools provided that the surfaces that come into contact with the austenitic and duplex stainless materials are protected with an austenitic or nickel base alloy.

7.2 Design

7.2.1 Care is to be exercised in the weld design to prevent crevice corrosion from occurring, particularly where austenitic materials are used. In this respect fillet welds and partial penetration welds are to be continuous and welded on both sides of the joint.

7.3 Forming and bending

7.3.1 Materials that are cold formed, such that the total strain exceeds 15 per cent (i.e. where the formed diameter to thickness ratio is less than 6:1) are to be subjected to a subsequent softening heat treatment in accordance with the material manufacturers recommendations, unless it is demonstrated by testing that the material properties are acceptable in the ‘as formed’ condition.

7.3.2 Materials may be hot formed provided that a subsequent softening heat treatment is carried out. The forming process and the subsequent heat treatment are to be in accordance with the material manufacturer’s recommendations.

7.4 Fabrication and welding

7.4.1 Welding may be performed using shielded manual arc welding (SMAW), gas tungsten arc welding (GTAW), MIG/MAG welding (GMAW), flux cored arc welding (FCAW), plasma arc welding (PAW) and submerged arc welding (SAW). The use of other welding processes will be subject to special consideration and will require submission of the process details, consumables and the weld properties achieved.

7.4.2 Misalignment may be corrected by the application of steady even force (e.g. using hydraulic or screw-type clamps). Hammering or heating is not permitted.

7.4.3 For full penetration welds, a backing or shielding gas is to be provided to prevent oxidation of the root weld. The backing gas is to be maintained until completion of, at least, the root and first fill layer. The backing gas may be omitted where the weld is back gouged or ground to remove the root weld.

7.4.4 Shielding and backing gases are to be an inert type of high purity and oxygen free.

7.4.5 For welding of Duplex stainless, the use of backing gases that contain up to 2 per cent nitrogen is permitted.

7.4.6 Welding of duplex stainless steels without filler metal is generally not permitted.

7.4.7 Degreasing agents, acid solutions, washing water etc. used for cleaning and any marking crayons and paints used are to be free of chlorides.

7.5 Repairs

7.5.1 Correction of distortion by the application of heat is not permitted.

■ *Section 8*
Specific requirements for welded aluminium

8.1 Scope

8.1.1 This Section specifies requirements for the fabrication and welding of aluminium alloys, and is in addition to those detailed in this Chapter.

8.1.2 Fabrication and welding of these materials is to be in designated areas which are separated from those used for other materials, such as carbon steels, stainless steels and copper alloys. Where work is performed in the same workshop as other materials, adequate barriers or screening are to be provided to prevent cross-contamination of different material types.

8.1.3 All tools and equipment used are to be suitable for use on aluminium alloy materials. The use of tools made of carbon steel materials is to be avoided where possible.

8.2 Forming and bending

8.2.1 Aluminium alloys are to be subject to cold forming and cold bending only.

8.3 Fabrication and welding

8.3.1 Welding may be performed using gas tungsten arc welding (GTAW) or metal inert gas welding (GMAW), MIG/MAG welding (GMAW), or variants thereof. The use of other welding processes such as friction stir welding (FSW) will be subject to special consideration and will require submission of the process details, consumables and the weld properties achieved.

8.3.2 A comparison of the mechanical properties for selected welded and unwelded alloys is given in *Table 13.8.1 Minimum mechanical properties for aluminium alloys*.

Table 13.8.1 Minimum mechanical properties for aluminium alloys

Alloy	Condition	0,2% proof stress, N/mm^2		Ultimate tensile strength, N/mm^2	
		Unwelded	Welded (*see* Note 4)	Unwelded	Welded (*see* Note 4)
5083	O/H111	125	125	275	275
5083	H112	125	125	275	275
5083	H116/H321	215	125	305	275
5383	O/H111	145	145	290	290
5383	H116/H321	220	145	305	290
5086	O/H111	100	95	240	240
5086	H112	125 (*see* Note 2)	95	250 (*see* Note 2)	240
5086	H116/H321	195	95	275	240
5059	O/H111	160	160	330	330

5059	H116/H321		260	160	360	300
5456	O		125	125	285	285
5456	H116		200 (*see* Note 5)	125	290 (*see* Note 5)	285
5456	H321		215 (*see* Note 5)	125	305 (*see* Note 5)	285
5754	O/H111		80	80	190	190
6005A	T5/T6	Extruded: Open Profile	215	100	260	160
(*see* Note 1)		Extruded: Closed Profile	215	100	250	160
6061	T5/T6	Rolled	240	125	290	160
(*see* Note 1)		Extruded: Open Profile	240	125	260	160
		Extruded: Closed Profile	205	125	245	160
6082	T5/T6	Rolled	240	125	280	190
		Extruded: Open Profile	260	125	310	190
		Extruded: Closed Profile	240	125	290	190

Note 1. These alloys are not normally acceptable for application in direct contact with sea-water.

Note 2. *See also Table 8.1.3 Minimum mechanical properties for acceptance purposes of selected rolled aluminium alloy products* or *Table 8.1.4 Minimum mechanical properties for acceptance purposes of selected extruded aluminium alloy products* in Chapter 8.

Note 3. The mechanical properties to be used to determine scantlings in other types and grades of aluminium alloy manufactured to National or proprietary Standards and specifications are to be individually agreed with LR, *see also Ch 8, 1.1 Scope 1.1.5*.

Note 4. Where detail structural analysis is carried out, 'unwelded' stress values may be used away from heat affected zones and weld lines, *see also Pt 3, Ch 2, 1.3 Aluminium 1.3.3* of the Rules for Ships.

Note 5. For thickness less than 12,5 mm, the minimum unwelded 0,2% proof stress is to be taken as 230 N/mm^2 and the minimum tensile strength is to be taken as 315 N/mm^2.

8.3.3 Misalignment may be corrected by the application of steady even force (e.g. using hydraulic or screw-type clamps). Hammering or heating is not permitted.

8.3.4 Correction of distortion by the application of heat is not permitted.

8.4 Non-destructive examination

8.4.1 The requirements of *Ch 13, 1.11 Non-destructive examination of welds* and *Ch 13, 2.12 Non-destructive examination of welds* apply; however, acceptance criteria applicable to aluminium are to be in accordance with *Table 13.8.2 Acceptance criteria for surface imperfections of aluminium* and *Table 13.8.3 Acceptance criteria for internal imperfections of aluminium*.

Table 13.8.2 Acceptance criteria for surface imperfections of aluminium

Surface discontinuity	Classification according to ISO 6520-1	Acceptance criteria
Crack	100	Not permitted
Lack of fusion	401	Not permitted
Incomplete root penetration in butt joints welded from one side	4021	Not permitted
Surface pore	2017	$d \leq 0{,}3s$ or $0{,}3a$ or 1,5 mm (whichever is the lesser)
Linear porosity (*see* Note 1)	2014	Not permitted
Uniformly distributed porosity (*see* Note 2)	2012	≤ 1% of area
Clustered porosity	2013	Not permitted
Continuous undercut	5011	$h \leq 0{,}1t$ or 0,5 mm (whichever is the lesser)
Intermittent undercut	5012	$h \leq 0{,}1t$ or 1,0 mm (whichever is the lesser)
Excess weld metal (*see* Note 3)	502	$h \leq 1{,}5$ mm + $0{,}15b$ or 8 mm (whichever is the lesser)
Excess penetration	504	$h \leq 4$ mm
Root concavity (*see* Note 3)	515	$h \leq 0{,}1t$ or 1 mm (whichever is the lesser)
Linear misalignment (*see* Notes 4 and 5)	507	$h \leq 0{,}1t$ or 1,0 mm (whichever is the lesser)
Angular misalignment	508	(*see* Note 6)

Symbols

a = nominal throat thickness of a fillet weld

b = width of weld reinforcement

d = diameter of a gas pore

h = height or width of an imperfection

s = nominal butt weld thickness

t = wall or plate thickness (nominal size)

Note 1. For these acceptance criteria, linear porosity is to be considered as three aligned gas pores in a length of 25 mm.

Note 2. To be in accordance with EN ISO 10042.

Note 3. A smooth transition is required.

Note 4. Linear misalignment is to be a maximum of 0,5 mm in highly stressed areas. For other areas, the linear misalignment is to be a maximum of 1,0 mm locally, where the sum of the length of imperfection is not more than 10% of the weld length.

Note 5. The limits for linear misalignment relate to deviations from the correct position. Unless otherwise specified, the correct position is that when the centrelines coincide.

Note 6. Angular misalignment shall be mutually agreed between the designer and the fabricator.

Table 13.8.3 Acceptance criteria for internal imperfections of aluminium

Internal discontinuity	Classification according to ISO 6520-1	Acceptance criteria (*see* Note 1)	
Crack	100	Not permitted	
Lack of fusion	401	Not permitted	
Incomplete penetration	402	Not permitted	
Single gas pore	2017	$d \leq 0{,}3s$ or $0{,}3a$ or 5 mm (whichever is the lesser)	
Linear porosity	2014	Assess as lack of fusion	
Uniformly distributed porosity (*see* Note 1)	2012	$0{,}5 < t < 3$ mm	≤ 2% of area
		$3 < t < 12$ mm	≤ 4% of area
		$12 < t < 30$ mm	≤ 6% of area
		$t > 30$ mm	≤ 8% of area
Clustered porosity (*see* Note 1)	2013	$dA \leq 20$ mm or wp (whichever is the lesser)	
Elongated cavity	2015	$l \leq 0{,}3s$ or $0{,}3a$ or 4 mm (whichever is the lesser)	
Wormhole	2016		
Oxide inclusion (*see* Note 2)	303	$l \leq 0{,}5s$ or $0{,}5a$ or 5 mm (whichever is the lesser)	
Tungsten inclusion	3041	$l \leq 0{,}3s$ or $0{,}3a$ or 4 mm (whichever is the lesser)	
Copper inclusion	3042	Not permitted	
Multiple imperfections in any cross-section	—	The sum of the acceptable individual imperfections in any cross-section is not to exceed $0{,}3t$ or $0{,}3a$ (whichever is the lesser)	

Symbols

a = nominal throat thickness of a fillet weld
b = width of weld reinforcement
d = diameter of a gas pore
h = height or width of an imperfection
s = nominal butt weld thickness
t = wall or plate thickness (nominal size)
wp = width of weld or width or height of cross-sectional area
dA = diameter of area surrounding gas pores
l = length of imperfection in longitudinal direction of weld

Note 1. Porosity is to be determined in accordance with ISO 10042. The requirements for a single gas pore are to be met by all the gas pores within this circle. Systematic clustered porosity is not permitted.

Note 2. If several oxide inclusions $l1$, $l2$, $l3$, ... exist in one cross-section, then they are summed: $l = l1 + l2 + l3 + \ldots + l_n$.

8.4.2 Alternative NDE acceptance criteria will be subject to special consideration provided that they are equivalent to these requirements.

Section 9
Friction stir welding requirements for aluminium alloys

9.1 Scope

9.1.1 The requirements of this Section apply to the application of FSW during construction.

9.1.2 Prior to welding, the friction stir welding equipment is to have been demonstrated as being suitable for use.

9.1.3 Qualified welding procedures that have been approved by LR are required. Procedures to ISO 25239-4 that are endorsed by another Classification Society may be accepted if they are to the satisfaction of the attending Surveyor.

9.1.4 Welding operators are to be qualified to ISO 25239-3 standard. Where qualifications have been certified by another Classification Society, acceptance of the qualifications will be subject to document review and demonstration of knowledge of the FSW process and function of the FSW installation.

9.2 Production quality control

9.2.1 The general requirements for quality control are specified in ISO 25239-5.

9.2.2 Unless otherwise specified in relevant parts of the Rules, the following production tests will be required.

9.2.3 A production test is required when there is a change in procedure, a change in tooling, after equipment repairs or modifications, after deviation from optimum parameters are detected, when defects are identified by non-destructive testing, after continuous welding of every 100 m length during a single shift and with a maximum interval between procedure tests of 8 hours. For butt welds the production tests are to consist of 100 per cent visual examination, two face bend tests, two root bend tests and one macro section. For thicknesses exceeding 12 mm, sets of face and bend tests may be replaced by side bend tests. For test assembly, *see Figure 13.9.1 Production test assembly for Friction Stir Welds*. The production tests for other joint geometry are to be agreed between the Surveyor and the fabricator.

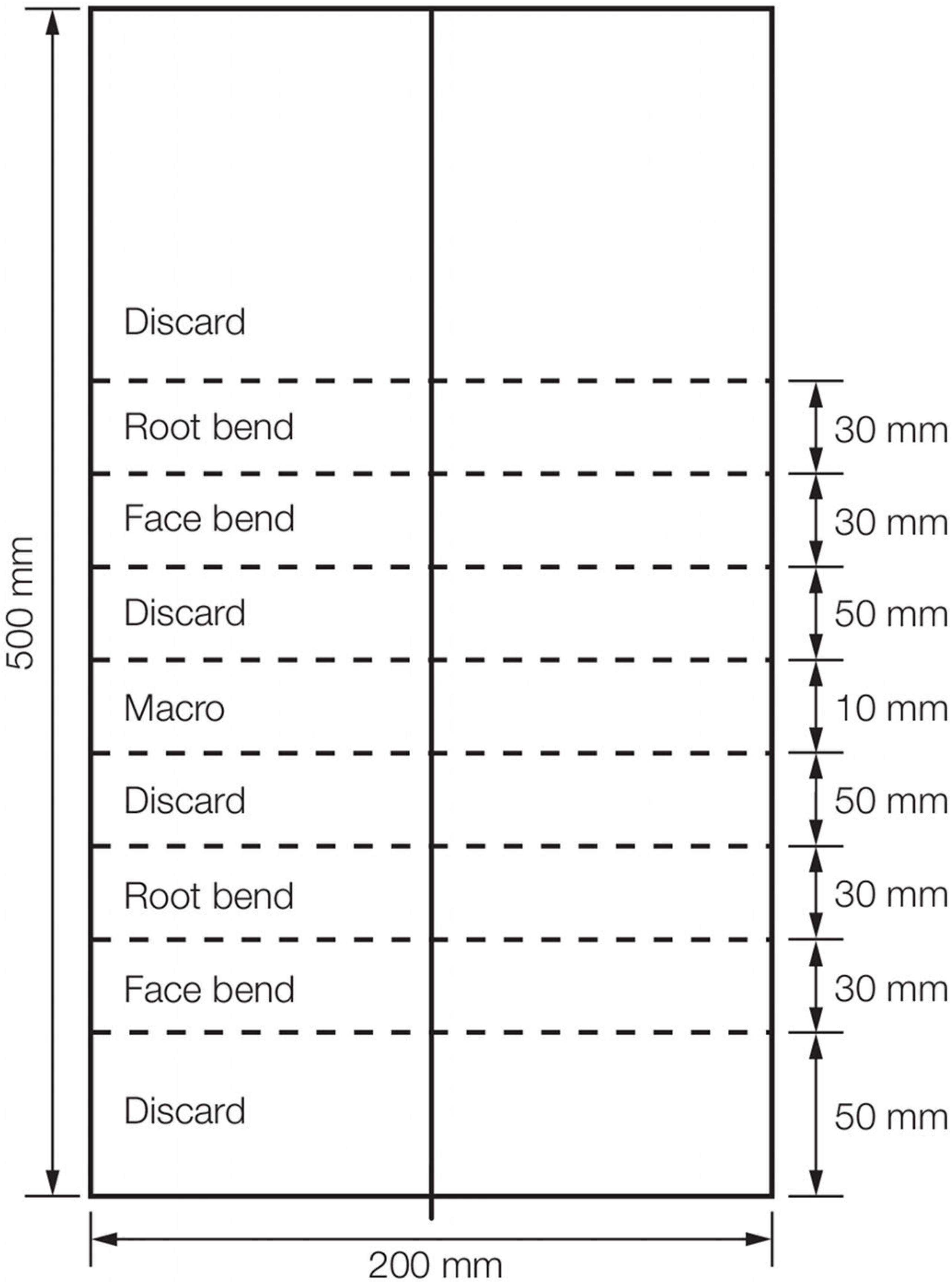


Figure 13.9.1 Production test assembly for Friction Stir Welds

9.2.4 As an automated process, all essential variables are to be recorded by the FSW system. The welding operator is responsible for ensuring that the system continues to produce welds that are in compliance with the qualified procedure. Surveyors are to be informed when the system exceeds the operating parameters. Surveyors are periodically to review the welding records.

9.2.5 Production welds are to be subject to 100 per cent visual examination by the fabricator and be subject to random checking by the Surveyor.

9.2.6 Surface and volumetric NDE testing is to be conducted on production welds at a frequency of two per welded panel or one every 100 m of weld, whichever is the greater.

9.2.7 Assessment of imperfections is to be in accordance with ISO 25239-5 Annex A and the requirements of *Table 13.8.3 Acceptance criteria for internal imperfections of aluminium*.

9.3 Repair

9.3.1 All defective welds are to be reported to the Surveyor.

9.3.2 The manufacturer is to have an approved procedure for the repair of defective welds.

9.3.3 Weld repairs are to be conducted by qualified welders or welding operators in accordance with qualified weld procedures. Welding procedures and welders/operators are to be qualified in accordance with the requirements of *Ch 12 Welding Qualifications* as appropriate to the welding process used for the weld repair.

9.3.4 All repairs are to be subject to 100 per cent visual, surface and volumetric NDE.

■ *Section 1* General requirements

1.1 Scope

1.1.1 Provision is made in this Chapter for the manufacture and testing of plastics pipes, together with approval requirements for base materials used in the construction or repair of composite vessels, other marine structures, piping and any associated machinery components and fittings which are to be certified or are intended for classification.

1.1.2 These materials and products are to be manufactured and surveyed in accordance with the general requirements of *Ch 14, 1 General requirements*, *Ch 14, 2 Tests on polymers, resins, reinforcements and associated materials* and *Ch 14, 3 Testing procedures* of this Chapter; and LR's *Materials and Qualification Procedures for Ships (MQPS) Book K*, *see Ch 1, 2.2 LR Approval – General 2.2.2*, which, in addition to the test programme, also details the procedures for application for approval of manufacturers and products and details of the information to be supplied by the manufacturer.

1.1.3 For base materials, the manufacturer's works do not require approval by Lloyd's Register (hereinafter referred as 'LR'), however the Quality Control procedures must be acceptable in accordance with the appropriate Section of this Chapter.

1.1.4 Where a requirement exists for the material to be approved, the test requirements and information to be submitted for approval of polymers, resins, reinforcements and associated materials are defined in *Ch 14, 2 Tests on polymers, resins, reinforcements and associated materials* and *Ch 14, 3 Testing procedures*.

1.1.5 Specific material requirements relating to the design and manufacture of plastics pipes and fittings are indicated in *Ch 14, 4 Plastics pipes and fittings*, with the material requirements for hull structures contained in *Ch 14, 5 Control of material quality for composite construction*.

1.1.6 For Builders constructing composite vessels, *Ch 14, 5 Control of material quality for composite construction* provides the minimum material control requirements for acceptance of the works by LR.

1.1.7 For the purposes of these Rules a 'plastics material' is regarded as an organic substance which may be thermosetting or thermoplastic and which, in its finished state, may contain reinforcements or additives.

1.1.8 Materials not listed in *Ch 14, 2.1 Scope 2.1.1* may be considered for approval on a case-by-case basis. The approved test results will be listed on the issued certificate. Subject to satisfactory service experience and validation of approval, the material may be entered in *Ch 14, 2.1 Scope 2.1.1* of the Rules.

1.2 Information on material quality and application

1.2.1 Where plastics products are to be classed or certified, the manufacturer is to provide the material producer with such information as is essential to ensure that the base materials to be used are in accordance with the approval requirements and the product specification. This information is to include any survey requirements for the materials.

1.3 Manufacture

1.3.1 Plastics products are to be made at works which have been approved (or accepted) for the type of product being supplied using base materials that have been approved.

1.3.2 Base materials are to be approved in accordance with the requirements of *Ch 14, 2 Tests on polymers, resins, reinforcements and associated materials* and *Ch 14, 3 Testing procedures*.

1.3.3 In order that a works can be approved (or accepted), the manufacturer is required to demonstrate to the satisfaction of LR that the necessary manufacturing and testing facilities are available and are supervised by qualified personnel. A specified programme of tests is to be carried out under the supervision of the Surveyors, and the results are to be to the satisfaction of LR. When a manufacturer has more than one works, the approval (or acceptance) is only valid for the individual works which carried out the test programme.

1.3.4 In order to maintain approval, the manufacturer is required to confirm in writing that there have been no changes in the formulation or production process for the material in question and that the site of manufacture remains unchanged.

1.4 Survey procedure

1.4.1 The Surveyors are to be allowed access to all relevant parts of the works and are to be provided with the necessary facilities and information to enable them to verify that manufacture is being carried out in accordance with the approved procedure. Facilities are also to be provided for the selection of test material, the witnessing of specified tests and the examination of materials, as required by the Rules.

1.4.2 Prior to the provision of test material for acceptance, manufacturers are to provide the Surveyors with details of the order, specification and any special conditions additional to the Rule requirements.

1.4.3 Before final acceptance, all test materials are to be confirmed as typical of the manufactured product and be submitted to the specified tests and examinations under conditions acceptable to the Surveyors. The results are to comply with the specification and any Rule requirements and are to be to the satisfaction of the Surveyors.

1.4.4 These specified tests and examinations are to be carried out prior to the despatch of finished products from the manufacturer's works.

1.4.5 In the event of any material proving unsatisfactory, during subsequent working, machining or fabrication, it is to be rejected, notwithstanding any previous certification.

1.5 Alternative survey procedure

1.5.1 Where materials are manufactured in quantity by semi-continuous or continuous processes under closely controlled conditions, an alternative system for testing and inspection may be adopted, subject to the agreement of the Surveyors.

1.5.2 In order to be considered for approval, manufacturers are to comply with the requirements of *Ch 1, 2 Approval and survey requirements*.

1.6 Post-cure heating

1.6.1 Post-cure heating is to be carried out in properly constructed ovens which are efficiently maintained and have adequate means for control and recording of temperature. The oven is to be such as to allow the whole item to be uniformly heated to the necessary temperature. In the case of very large components which require post-cure heating, alternative methods will be specially considered.

1.7 Test material

1.7.1 Sufficient material is to be provided for the preparation of the test specimens detailed in the specific requirements. It is, however, in the interests of manufacturers to provide additional material for any re-tests which may be necessary, as insufficient or unacceptable test material may be a cause for rejection.

1.7.2 Where test materials, (either base materials or product sample materials) are selected by the Surveyor or a person nominated by LR, these are to be suitably identified by markings which are to be maintained during the preparation of the test specimens.

1.7.3 All base material samples for testing are to be prepared under conditions that are as close as possible to those under which the product is to be manufactured. Where this is not possible, a suitable procedure is to be agreed with the Surveyor.

1.7.4 During production, check test samples are to be provided as requested by the Surveyor.

1.7.5 Should the taking of these samples prove impossible, model samples are to be prepared concurrently with production. The procedure for the preparation of these samples is to be agreed with the Surveyor.

1.7.6 The dimensions, number and orientation of test specimens are to be in accordance with the requirements of a National or International Standard acceptable to LR.

1.8 Re-test procedure

1.8.1 Where test material fails to meet the specified requirement, two additional tests of the same type may be made at the discretion of the Surveyor.

1.8.2 Where an individual test result in a group (minimum five) deviates from the mean by more than two standard deviations in either the higher or lower direction, the result is to be excluded and a re-test made. Excluded results of tests are to be reported with confirmation that they have been excluded. Only one exclusion is acceptable in any group of tests.

1.9 Visual and non-destructive examination

1.9.1 Prior to the final acceptance, surface inspection, verification of dimensions and non-destructive examination are to be carried out in accordance with the requirements detailed in *Ch 14, 3 Testing procedures*, *Ch 14, 4 Plastics pipes and fittings* and *Ch 14, 5 Control of material quality for composite construction* of this Chapter.

1.9.2 When there is visible evidence to doubt the soundness of any material or component, such as flaws or suspicious surface marks, it is to be the responsibility of the manufacturer to prove the quality of the material by any suitable method.

1.10 Rectification of defective material

1.10.1 Small surface blemishes may be removed by mechanical means provided that, after such treatment, the dimensions are acceptable, the area is proved free from structural defects and the rectification has been completed to the satisfaction of the Surveyor.

1.10.2 Repair procedures for larger defects are to be agreed with LR prior to implementation.

1.11 Identification of products and base materials

1.11.1 The manufacturer of approved materials is to identify each batch with a unique number.

1.11.2 The manufacturer of plastics products is to adopt a system of identification which will enable all finished products to be traced to the original batches of base materials. Surveyors are to be given full facilities for tracing any component or material when required.

1.11.3 When any item has been identified by the personal mark of a Surveyor, or deputy, this is not to be removed until an acceptable new identification mark has been made by a Surveyor. Failure to comply with this condition will render the item liable to rejection.

1.11.4 Before any pipe or fitting is finally accepted it is to be clearly marked by the manufacturer in at least one place with the particulars detailed in the appropriate specific requirements as given in *Ch 14, 4 Plastics pipes and fittings*.

1.11.5 Where a number of identical items are securely fastened together in bundles, the manufacturer need only brand the top item of each bundle. Alternatively, a durable label giving the required particulars may be attached to each bundle.

1.12 Certification

1.12.1 Certification of the finished product is to be in accordance with the requirements of the appropriate Sections.

■ *Section 2*
Tests on polymers, resins, reinforcements and associated materials

2.1 Scope

2.1.1 This Section gives the tests and data required by LR for materials approval and/or inspection purposes on the following:

(a) Thermoplastic polymers.
(b) Thermosetting resins.
(c) Reinforcements.
(d) Reinforced thermoplastic polymers.
(e) Reinforced thermosetting resins.
(f) Core materials.
   (i) End-grain balsa.
   (ii) Rigid foams.

(iii) Synthetic felt type materials.

(g) Machinery chocking compounds.
(h) Rudder and pintle bearings.
(i) Stern tube bearings.
(j) Plywoods.
(k) Adhesive and sealant materials.
(l) Repair compounds.

2.2 Thermoplastic polymers

2.2.1 The following data is to be provided by the manufacturer for each thermoplastic polymer:

(a) Melting point.
(b) Melt flow index.
(c) Density.
(d) Bulk density.
(e) Filler content, where applicable.
(f) Pigment content, where applicable.
(g) Colour.

2.2.2 Samples for testing are to be prepared by moulding or extrusion under the polymer manufacturer's recommended conditions.

2.2.3 The following tests are to be carried out on these samples:

(a) Tensile stress at yield and break.
(b) Modulus of elasticity in tension.
(c) Tensile strain at yield and break.
(d) Compressive stress at yield and break.
(e) Compressive modulus.
(f) Temperature of deflection under load.
(g) Determination of water absorption.

2.3 Thermosetting resins

2.3.1 The data listed in *Table 14.2.1 Data requirements for thermosetting resins* is to be provided by the manufacturer for each thermosetting resin.

Table 14.2.1 Data requirements for thermosetting resins

Data	Type of resin		
	Polyester (*See* Note 3 for vinylester)	Epoxide	Phenolic
Specific gravity of liquid resin	required	required	required
Viscosity	required	required	required
Gel time	required	required	not applicable
Appearance	required	required	required
Mineral content (*see* Note 1)	required	required	not applicable (*see* Note 2)
Volatile content	required	not applicable	not applicable
Acid value	required	not applicable	not applicable
Epoxide content	not applicable	required	not applicable

Free phenol	not applicable	not applicable	required
Free formaldehyde	not applicable	not applicable	required
Note 1. This is to be the total filler in the system, including thixotrope, filler, pigments, etc. and is to be expressed in parts by weight per hundred parts of pure resin.			
Note 2. If the resin is pre-filled, the mineral content is required.			
Note 3. Vinylesters are to be treated as equivalent to polyesters.			

2.3.2 Cast samples are to be prepared in accordance with the manufacturer's recommendations and are to be cured and post-cured in a manner consistent with the intended use. The curing system used and the ratio of curing agent (or catalyst) to resin are to be recorded. Where post-cure conditions equivalent to ambient-cure conditions apply, *see Ch 14, 3.2 Preparation of test samples 3.2.2* and *Ch 14, 3.2 Preparation of test samples 3.2.3*.

2.3.3 The following are to be determined using these samples:

(a) Tensile strength (stress at maximum load) and stress at break.
(b) Tensile strain at maximum load.
(c) Tensile secant modulus at 0,5 per cent and 0,25 per cent strain respectively.
(d) Temperature of deflection under load.
(e) Barcol hardness.
(f) Determination of water absorption.
(g) Volume shrinkage after cure.
(h) Specific gravity of cast resin.

2.3.4 In addition, for gel coat resins the stress at break and modulus of elasticity in flexure are to be determined.

2.3.5 Where resins which have been modified by the addition of waxes or polymers, for example ‘low styrene emission or air inhibited’ materials, it is to be confirmed that the use of such resins will not result in poor interlaminar adhesion when interruptions to the laminating process occur. The test procedure is to be as follows:

(a) A conventional room temperature curing catalyst/ accelerator system is to be used with the resin for laminate preparation.
(b) A laminate of 25 to 35 per cent glass content in mass is to be prepared using two plies of 450 g/m^2 chopped strand mat. The laminate is to be prepared at ambient temperature (18° to 21°C). The laminate is to be allowed to stand for a minimum of four days but no longer than 6 days at ambient temperature.
(c) A further two plies of 450 g/m^2 chopped strand mat are to be laminated onto the exposed surface and cured at ambient temperature for 24 hours. The finished laminate is then to be post-cured at 40°C for 16 hours. The finished laminate is to have a glass content of 25 to 35 per cent.
(d) After cooling, the apparent interlaminar shear strength of the laminate is to be determined in accordance with ISO 14130; the minimum value is given in *Ch 14, 5.11 Minimum tested requirements for material approval 5.11.4*. Before testing the samples shall be conditioned at 23°C and relative humidity of 50 per cent for a period of 88 hours before testing.
(e) If the tests are undertaken at the resin manufacturer’s own laboratory, the individual test values are to be reported and the broken test specimens retained for examination by LR.

Alternative test procedures will be considered with prior agreement.

2.4 Reinforcements

2.4.1 The following data is to be provided, where applicable, for each type of reinforcement:

(a) Reinforcement type.
(b) Fibre type for each direction.
(c) Fibre tex value.
(d) Fibre finish and/or treatment.
(e) Yarn count in each direction.
(f) Width of manufactured reinforcement.
(g) Weight per unit area of manufactured reinforcement.
(h) Weight per linear metre of manufactured reinforcement.
(i) Compatibility (e.g. suitable for polyesters, epoxides, etc.).

(j) Constructional stitching – details of yarn, specific gravity, type, frequency and direction.
(k) Weave type.
(l) Binder type and content.
(m) Density of the fibre material.

2.4.2 Tests of the mechanical properties are to be made on laminate samples containing the reinforcement and prepared as follows:

(a) an approved resin of suitable type is to be used;
(b) a minimum of three layers of the reinforcement is to be laid with parallel ply to give a laminate not less than 4 mm thick;
(c) the weights of resin and reinforcement used are to be recorded together with the measured thickness of the laminate, including the measured weight per unit area of the reinforcement used;
(d) for glass reinforcements, the glass/resin ratios, by weight, as shown in *Table 14.2.2 Glass fraction by weight for different reinforcement types* are to be used;
(e) for reinforcement type other than glass, a fibre volume fraction, as shown in *Table 14.2.3 Content by volume for different reinforcement types*, is to be used.

Table 14.2.2 Glass fraction by weight for different reinforcement types

Reinforcement type	Glass fraction nominal values
Unidirectional	0,60
Chopped strand mat	0,30
Woven roving	0,50
Woven cloth	0,50
Composite roving (*see* Note)	0,45
Gun rovings	0,33
±45° stitched parallel plied roving	0,50
Triaxial parallel plied roving	0,50
Quadriaxial parallel plied roving	0,50
Note Continuous fibre reinforcement with attached chopped strand mat.	

2.4.3 Rovings intended for filament winding are to be tested as unidirectional rovings.

Table 14.2.3 Content by volume for different reinforcement types

Reinforcement type	Content by volume nominal values
Unidirectional	0,41
Chopped strand mat	0,17
Woven roving	0,32
Woven cloth	0,32
Composite roving (*see* Note)	0,28
Gun rovings	0,19
±45° stitched parallel plied roving	0,32
Triaxial parallel plied roving	0,32

Quadriaxial parallel plied roving	0,32
Note The volume content may be converted to weight fractions by use of the formula: $W_F = V_F D_F/(D_F V_F + D_R V_R)$ where W_F = fibre fraction by weight D_F = density of fibre D_R = density of cured resin V_F = fibre fraction by volume V_R = resin fraction by volume	

2.4.4 The following tests as defined in *Ch 14, 3 Testing procedures* are to be made on the samples:

(a) Tensile strength (stress at maximum load).
(b) Tensile strain at break.
(c) Tensile secant modulus at 0,5 per cent and 0,25 per cent strain respectively.
(d) Compressive strength (stress at maximum load).
(e) Compressive modulus.
(f) Flexural strength (stress at maximum load).
(g) Modulus of elasticity in flexure.
(h) Apparent interlaminar shear.
(i) Fibre content.
(j) Determination of water absorption.

2.4.5 The laminate is to be tested in air in the directions indicated by *Table 14.2.4 Fibre orientations in reinforced test specimens*.

Table 14.2.4 Fibre orientations in reinforced test specimens

Type of reinforcement	Test orientations
Unidirectional	0°
Chopped strand mat Gun roving	any direction
Woven roving Woven cloth Composite roving	0° and 90°
± 45° parallel plied roving Triaxial plied roving Quadriaxial plied roving	0°, 45°, 90° and -45°

2.4.6 Additionally, tests in *Ch 14, 2.4 Reinforcements 2.4.4* are to be repeated, in one direction only, after immersion in fresh water at 35°C for 28 days with the exception of *Ch 14, 2.4 Reinforcements 2.4.4*.

2.5 Reinforced thermoplastic polymers

2.5.1 Thermoplastic polymers intended for use with reinforcements are to be tested in accordance with *Ch 14, 2.2 Thermoplastic polymers 2.2.1*.

2.5.2 A laminate is to be prepared using the polymer and an approved reinforcement in accordance with a manufacturing specification. The laminate is to be tested in accordance with the appropriate requirements of *Ch 14, 2.4 Reinforcements 2.4.4*. Testing may be confined to one direction only.

2.6 Reinforced thermosetting resins

2.6.1 Thermosetting resins intended for use with reinforcements are to be tested in accordance with *Ch 14, 2.3 Thermosetting resins 2.3.1*.

2.6.2 No further tests are required for gel coat resins.

2.6.3 For laminating resins, a laminate is to be prepared using the resin and an approved reinforcement as follows:

(a) For polyester resins, chopped strand mat.
(b) For epoxide resins, a balanced woven roving.

(c) For phenolic resins, a balanced woven material.

2.6.4 The laminate is to be tested in accordance with procedures outlined in MQPS Book K procedure 14-1 and *Ch 14, 2.4 Reinforcements 2.4.4* in one fibre direction only.

2.7 Core materials

2.7.1 **General requirements**. The following data is to be provided for each type of core material:

(a) Type of material.
(b) Density.
(c) Description (block, scrim mounted, grooved).
(d) Thickness and tolerance.
(e) Sheet/block dimensions.
(f) Surface treatment.

2.7.2 Manufacturers are required to provide a full application procedure for use of the product.

2.8 Specific requirements for end-grain balsa

2.8.1 The supplier is to provide a signed statement that the balsa (ochroma lozopus) is cut to end-grain, is of good quality, being free from unsound or loose knots, holes, splits, rot, pith and corcho, and that it has been treated against fungal and insect attack, shortly after felling, followed by homogenisation, sterilisation and kiln drying to an average moisture content of no more than 12 per cent.

2.8.2 The following tests are to be carried out on the virgin material, both parallel to and perpendicular to the grain:

(a) Compressive strength (stress at maximum load).
(b) Compressive modulus of elasticity.
(c) Tensile strength (stress at maximum load).

The density of the virgin material is also to be tested.

2.8.3 Where the balsa is mounted on a carrier material (e.g. scrim), any adhesive used is to be of a type compatible with the proposed resin system.

2.8.4 Core shear properties are to be determined according to the requirements of *Ch 14, 3.8 Structural core materials 3.8.1*.

2.9 Specific requirements for rigid foams (PVC, Polyurethane and other types)

2.9.1 The foam is to be of the closed cell type and compatible with the proposed resin system (e.g. polyester, epoxide etc.).

2.9.2 Foams are to be of uniform cell structure.

2.9.3 Data is to be provided on the dimensional stability of the foam by measurement of the shrinkage.

2.9.4 The following test data is to be submitted for each type of foam:

(a) Density.
(b) Tensile strength (stress at maximum load).
(c) Tensile modulus of elasticity.
(d) Compressive strength (stress at maximum load).
(e) Compressive modulus of elasticity.

2.9.5 Core shear properties are to be determined according to the requirements of *Ch 14, 3.8 Structural core materials 3.8.1*.

2.9.6 Additionally, the compressive properties (*see Ch 14, 2.9 Specific requirements for rigid foams (PVC, Polyurethane and other types) 2.9.4* and *Ch 14, 2.9 Specific requirements for rigid foams (PVC, Polyurethane and other types) 2.9.4*) are to be determined at a minimum of five points over the temperature range ambient to maximum recommended service or 70°C, whichever is the greater.

2.10 Synthetic felt type materials with or without microspheres

2.10.1 For materials of this type, the following data is required in addition to the requirements of *Ch 14, 2.7 Core materials 2.7.1*:

(a) Fibre type.
(b) Width.

(c) Width of finished material.
(d) Weight per unit area of the manufactured material.
(e) Weight per linear metre of the manufactured material.
(f) Compatibility.
(g) Details of the method of combining.

2.10.2 A laminate of the material is to be prepared using a suitable approved resin under conditions recommended by the manufacturer.

2.10.3 The following properties are to be determined:

(a) Tensile strength (stress at maximum load).
(b) Tensile strain at break.
(c) Modulus of elasticity in tension or secant modulus at 0,25 per cent and 0,5 per cent strain.
(d) Compressive strength (stress at maximum load).
(e) Compressive modulus.
(f) Flexural strength (stress at maximum load).
(g) Modulus of elasticity in flexure.
(h) Fibre content.
(i) Water absorption.

2.10.4 In the case of anisotropic materials (e.g. where combined with other reinforcements) the tests listed in *Ch 14, 2.10 Synthetic felt type materials with or without microspheres 2.10.3* are to be conducted in the 0°, 90° directions and in any other reinforcement direction.

2.10.5 Additionally, the tests listed in *Ch 14, 2.10 Synthetic felt type materials with or without microspheres 2.10.3* are to be repeated after immersion in fresh water at 35°C for 28 days. For anisotropic materials, the requirement is for this test to be carried out in one direction only.

2.10.6 The shear properties (of the resin filled system) are to be determined according to *Ch 14, 3.8 Structural core materials 3.8.1*.

2.11 Machinery chocking compounds (resin chocks)

2.11.1 Thermosetting materials for filling the space between the base of machinery and its foundation where the maintenance of accurate alignment is necessary are to be approved by LR before use.

2.11.2 Approval will be considered by LR for use under the following service conditions:

- Loading of 3,5 N/mm^2 (max) for a temperature not exceeding 60°C.
- Loading of 2,5 N/mm^2 (max) for a temperature not exceeding 80°C.
- Other loading conditions.

2.11.3 The exotherm temperature, defined as the maximum temperature achieved by the reacting resin under conditions equivalent to those of intended use, is to be determined according to a procedure approved by LR.

2.11.4 The following properties are to be determined on chock material cured at the measured exotherm temperature:

(a) The impact resistance (Izod).
(b) Hardness.
(c) Compressive strength (stress at maximum load) and modulus of elasticity.
(d) Water absorption.
(e) Oil absorption.
(f) Heat deflection temperature.
(g) Compressive creep is to be measured according to *Ch 14, 3.9 Machinery chocking compounds 3.9.4*.
(h) Curing linear shrinkage.
(i) Flammability.

2.11.5 The chocking compound approval is contingent on the material achieving the minimum exotherm value as specified when used on an installation under practical conditions.

2.11.6 Where the resin chock is to be used for installation of sterntubes and sternbushes in addition to the requirements of *Ch 14, 2.11 Machinery chocking compounds (resin chocks) 2.11.4*, the tensile strength and modulus of elasticity in tension are to be measured.

2.11.7 The manufacturer's installation procedure is required to be documented and is to be to the satisfaction of LR.

2.11.8 Resin chock materials are to be tested in accordance with *Ch 14, 3.9 Machinery chocking compounds* and are to meet the requirements of *Ch 14, 5.14 Synthetic chocking compounds*.

2.12 Rudder and pintle bearings

2.12.1 Materials used for rudder and pintle bearings are to be approved by LR before use.

2.12.2 Initial approval is to be based on a review of the following physical properties of the material:

(a) Compressive strength (stress at maximum load) and modulus of elasticity.
(b) Tensile strength (stress at maximum load) and modulus of elasticity.
(c) Shear strength (stress at maximum load).
(d) Impact strength.
(e) Swelling in oil and in water.
(f) Hardness.

2.12.3 Additionally, friction data is to be provided under both wet and dry conditions.

2.12.4 Furthermore, the installation instructions (especially recommended clearances) are to be reviewed by LR prior to provisional approval being given.

2.12.5 If the above data is satisfactory, the material will be provisionally approved until sufficient service experience has been gained.

2.13 Sterntube bearings

2.13.1 Materials used for sterntube bearings are to be approved by LR before use.

2.13.2 Approval is to be based on a review of the physical properties as given by *Ch 14, 2.12 Rudder and pintle bearings 2.12.2*.

2.13.3 Friction data is to be provided under the lubrication system(s) proposed for the material(s).

2.14 Plywoods

2.14.1 All plywoods are to be approved to BS 1088 or equivalent National or International Standard in accordance with LR's Type Approval Procedure.

2.14.2 For structural applications in the marine environment, a minimum timber rating of moderate durability according to BS 1088-1 and BS 1088-2 is required.

2.14.3 Enhancement of durability by use of preservatives is permitted, subject to each veneer layer being treated with a recognised preservative.

2.14.4 Where Okoume, as specified by BS 1088 is involved, (i.e. non-durable timber classification) this may only be used for marine structures subject to the specific application being acceptable to LR.

2.15 Adhesive and sealant materials

2.15.1 Materials of these types are to be accepted by LR before use.

2.15.2 The requirements for acceptance are dependent on the nature of the application.

2.15.3 In the first instance, the manufacturer is to submit full details of the product, procedure for method of use (including surface preparation) and the intended application. After review of these details, LR will provide a specific test schedule for confirmation of the material's properties.

2.15.4 Any acceptance granted will be limited to specific applications and will be contingent on the instructions for use being adhered to.

2.16 Repair compounds

2.16.1 Materials used for repairs are to be accepted by LR before use.

2.16.2 For acceptance purposes, the manufacturer is to submit full product details and user instructions, listing the types of repair for which the system is to be used together with details of any installer accreditation schemes.

2.16.3 Dependent on the proposed uses, LR may require testing in accordance with a specified test programme.

2.16.4 Materials will not be accepted for the following uses unless specific evidence of their suitability is provided:

(a) Any component in rubbing contact.
(b) Any component subject to dynamic cyclic loading.
(c) Any pressure part in contact with gas or vapour.
(d) Any pressure part in contact with liquid above 3,5 bar.
(e) Any component where operating temperature exceeds 90°C.

All uses of materials of these types are subject to the discretion of the Surveyor.

■ *Section 3* Testing procedures

3.1 General

3.1.1 This Section gives details of the test methods to be used for base materials and on finished plastics products such as fibre reinforced plastics (FRP) piping and any testing required in the construction of composite vessels.

3.1.2 In general, testing is to be carried out by a competent independent test house which, at the discretion of LR, may or may not require witnessing by the Surveyor.

3.1.3 Alternatively, testing may be carried out by the manufacturer subject to these tests being witnessed by the Surveyor.

3.1.4 All testing is to be carried out by competent personnel.

3.1.5 Unless specified otherwise, testing is to be carried out in accordance with a recognised ISO standard, where one exists, and all test programmes are to have written procedures.

3.1.6 Alternatively, testing may be carried out in accordance with a National Standard provided that it conforms closely to an appropriate ISO standard and subject to prior agreement with the Surveyor.

3.1.7 Mechanical properties are to be established using suitable testing machines of approved types. The machines and other test equipment are to be maintained in a satisfactory and accurate condition and are to be recalibrated at approximately annual intervals. Calibration is to be undertaken by a nationally recognised authority or other organisation of standing and is to be to the satisfaction of the Surveyor. A record of all calibrations is to be kept available in the test house. The accuracy of test machines is to be within ± one per cent.

3.2 Preparation of test samples

3.2.1 Thermoplastic samples are to be prepared in accordance with the manufacturer's recommendations for moulding. For finished products, samples are to be taken from the product during production in accordance with the manufacturer's quality plan, but where this is impractical, separate test samples are to be prepared in a manner identical with that of the product.

3.2.2 Samples of thermosetting resins are to be prepared using the curing system recommended by the manufacturer and identical with that used for the finished product.

3.2.3 The post curing conditions for samples of thermosetting resins are to be as recommended by the manufacturer and identical with those used for the finished product. Where the samples are made for the general approval of a resin, the post curing conditions are to be those in which the resin is intended to be used.

3.2.4 Where curing of the product is intended to take place at room temperature, the sample is to be allowed to cure at room temperature (18 to 21°C) for 24 hours followed by a post-cure at 40°C for 16 hours.

3.2.5 Where a reinforcement is to be used, the ratio of reinforcement to resin or polymer is to be nominally the same as that of the finished product or in accordance with *Table 14.2.2 Glass fraction by weight for different reinforcement types* or *Table 14.2.3 Content by volume for different reinforcement types*.

3.2.6 Where laminates are prepared specifically for approval test purposes, the reinforcement is to be laid parallel plied.

3.3 Preparation of test specimens

3.3.1 The test specimen is to be prepared in accordance with the appropriate ISO standard and the requirements of this Section.

3.3.2 Precautions are to be taken during machining to ensure that the temperature rise in the specimen is kept to a minimum.

3.4 Testing

3.4.1 Strain measurement is to be made by the use of a suitable extensometer or strain gauge.

3.4.2 The rate of strain is to be in accordance with the appropriate ISO standard.

3.4.3 The number of test specimens from each sample to be tested is to be in accordance with the ISO standard. For mechanical testing this is five.

3.5 Discarding of test specimens

3.5.1 If a test specimen fails because of faulty preparation or incorrect operation of the testing machine, it is to be discarded and replaced by a new specimen.

3.5.2 In addition, if the deviation of one result in a group of five exceeds the mean by more than two standard deviations, that result is to be discarded and one further specimen tested, *see Ch 14, 1.8 Re-test procedure 1.8.1* and *Ch 14, 1.8 Re-test procedure 1.8.2*.

3.6 Reporting of results

3.6.1 All load/displacement graphs and tabulated results are to be reported, including mean values and the calculated standard deviation.

3.6.2 Additionally, full details of the sample and specimen preparation are to be provided including (where applicable):

(a) Catalyst/accelerator or curing agent types and mix ratio.
(b) Weights of resins, and/or reinforcements used.
(c) Casting/laminate dimensions.
(d) Number of layers of reinforcement used.
(e) Curing/post-curing conditions.

3.7 Tests for specific materials

3.7.1 The data requirements in *Ch 14, 2.2 Thermoplastic polymers* and *Ch 14, 2.3 Thermosetting resins* for thermoplastic or thermosetting resins or polymers are to be determined in accordance with suitable National or International Standards.

3.7.2 Recognised Standards to which specimens of unreinforced thermoplastic resins are to be tested are listed in *Table 14.3.1 Tests for unreinforced thermoplastic resins*.

Table 14.3.1 Tests for unreinforced thermoplastic resins

Test	Standard	
Tensile properties	ISO 527-2:1993	Test speed = 5 mm/min Specimen 1A or 1B
Flexural properties	ISO 178:2001	Test speed = $\frac{Thickness}{2}$ mm/min
Water absorption	ISO 62:2008	Method 1
Temperature of deflection under load	ISO 75-2:2004	Method A
Compressive properties	ISO 604:2002	Test speed - as for ductile materials
Note 1. Water absorption - result to be expressed as milligrams. Note 2. Tensile modulus values are to be determined using an extensometer which may be removed for strain to failure.		

3.7.3 Test standards for unreinforced cast thermosetting resins are given in *Table 14.3.2 Tests on unreinforced cast thermoset resin specimens*.

Table 14.3.2 Tests on unreinforced cast thermoset resin specimens

Test	Standard	
Tensile properties	ISO 527-2:1993	Test speed = 5 mm/min Specimen 1A or 1B
Flexural properties	ISO 178:2001	Test speed = $\frac{Thickness}{2}$ mm/min
Water absorption	ISO 62:2008	Method 1
Temperature of deflection under load	ISO 75-2:2004	Method A
Compressive properties	ISO 604:2002	Test speed = 1 mm/min
Note 1. ISO 62:2008 - where resins are intended for use under ambient conditions to avoid additional post-curing, the requirement in ISO 62:2008 for pre-drying the test specimen at 50°C is to be omitted. The test result is to be expressed as mg of water. Note 2. ISO 527-2:1993 - tensile properties are to be measured using extensometry.		

3.7.4 The Standards to which laminate specimens of any type are to be tested are listed in *Table 14.3.3 Tests on laminate specimens*.

Table 14.3.3 Tests on laminate specimens

Test	Standard	
Tensile properties	ISO 527-4:1997	Test speed = 2 mm/min Specimen types II or III
Flexural properties	ISO 14125:1998	Test speed = $\frac{Thickness}{2}$ mm/min Method A
Compressive properties	ISO 604:2002	Test speed = 1 mm/min
Interlaminar shear	ISO 14130:1997	
Water absorption	ISO 62:2008	Method 1
Glass content	ISO 1172:1996	
Note 1. ISO 62:2008 - where resins are intended for use under ambient conditions to avoid additional post-curing, the requirement in ISO 62:2008 for pre-drying the test specimen at 50°C is to be omitted. The test result is to be expressed as mg of water. Note 2. ISO 527-4:1997 - tensile properties are to be measured using extensometry. Note 3. Tensile modulus values are to be determined using an extensometer which may be removed for strain to failure.		

3.8 Structural core materials

3.8.1 Initially, the core shear strength and modulus are to be determined by ISO 1922:2001 or ASTM C273/C273M. Test sandwich panels are then to be prepared and subjected to four-point flexural tests to determine the apparent shear properties according to ASTM C393/C393M:06 (short beam) at two representative thicknesses (i.e. 15 mm and 30 mm). Testing is to be carried out at ambient temperature and at 70°C. The following requirements are to be observed:

(a) Each skin is to be identical and have a thickness not greater than 21 per cent of the nominal core thickness. For hand laid constructions, each skin is to comprise a lightweight chopped strand mat reinforcement (300 g/m^2) consolidated at a glass content, by weight, of 0,3 against the core, plus the required number of woven reinforcements consolidated, using an isophthalic polyester resin, to give a minimum glass content, by weight, of 0,5.
(b) The method of construction of the sandwich laminate is to reflect the core material manufacturer's instructions for use, i.e. application of bonding paste, surface primer or any other recommended system.
(c) Where vacuum bagging techniques or equivalent systems are used, these will be subject to individual consideration.
(d) All resins and reinforcements are to hold current LR approval.

(e) Curing conditions are to be in accordance with *Ch 14, 3.2 Preparation of test samples 3.2.3* and *Ch 14, 3.2 Preparation of test samples 3.2.4*.

(f) The dimensions of the test samples should be based on the requirements of ASTM C393 Paragraph 5.1, and the ratio parameters as indicated in ASTM C393 Paragraph 5.2, using a proportional limit stress (*F*) for the woven roving skins of 130 N/mm^2 and a span (a_2) of not less than 400 mm.

3.8.2 For each type of test sample, the following data are to be reported, together with the submission of a representative test sample showing the mode of failure for each density of core material:

(a) Skin and core thickness, and core type and density.

(b) Resin/catalyst/accelerator ratio.

(c) Skin construction, including types and weight of reinforcements, resin(s), etc.

(d) Details of production method and curing conditions (temperature and times).

(e) Where additional preparation of the foam is involved, for example the use of primers or bonding pastes, full details are to be provided.

(f) Actual span between base supports for each type of test sample.

3.8.3 The following requirements apply to end-grain balsa:

(a) The data requirements of *Ch 14, 2.7 Core materials 2.7.1* are to be provided, where applicable, according to suitable National or International Standards.

(b) The balsa is to be tested according to the requirements of *Ch 14, 3.8 Structural core materials 3.8.1*.

(c) The test methods for balsa are given in *Table 14.3.4 Tests on end-grain balsa*.

Table 14.3.4 Tests on end-grain balsa

Test	Standard
Density	ISO 845:2006
Tensile properties	ASTM C297/C297M:04 Test speed = $\frac{Thickness}{10}$ mm/min
Compressive properties	ISO 844:2007 Test speed = $\frac{Thickness}{10}$ mm/min
Shear properties	ISO 1922:2001 Test speed = 1 mm/min

3.8.4 The following requirements apply to rigid foams:

(a) The data requirements of *Ch 14, 2.7 Core materials 2.7.1* are to be provided in accordance with a suitable National or International Standard.

(b) The foam is to be tested according to the requirements of *Ch 14, 3.8 Structural core materials 3.8.1*.

(c) The test methods for rigid foams are to be in accordance with *Table 14.3.4 Tests on end-grain balsa*.

3.8.5 The following requirements apply to synthetic felt type materials:

(a) The data requirements of *Ch 14, 2.10 Synthetic felt type materials with or without microspheres 2.10.1* are to be provided according to suitable National or International Standards.

(b) The material is to be tested according to the requirements of *Ch 14, 3.8 Structural core materials 3.8.1*, with the following modifications:

  (i) The core of the laminate test sandwich panel is to be prepared with a fibre content as recommended by the manufacturer.

  (ii) The felt fibre/resin ratio is to be stated.

  (iii) The required test thicknesses of the cores are to be changed from 30 mm and 15 mm to 12 mm and 6 mm respectively.

(c) The prepared laminate of the base material is to be of minimum thickness 3,5 mm with a minimum of three layers.

(d) The specified tests on the laminate (*see Ch 14, 2.10 Synthetic felt type materials with or without microspheres 2.10.1*) are to be conducted according to the requirements of *Table 14.3.3 Tests on laminate specimens*.

3.9 Machinery chocking compounds

3.9.1 Test samples of the cured chock resin are to be prepared under ambient conditions and then post-cured at the exotherm temperature as determined in *Ch 14, 2.11 Machinery chocking compounds (resin chocks) 2.11.3*.

3.9.2 The specified properties are to be determined as required by *Table 14.3.5 Tests for machinery chocking components*.

Table 14.3.5 Tests for machinery chocking components

Test	Standard
Izod Impact Resistance	ISO 180-2000 Unnotched
Barcol hardness	ASTM D2583-07 or BS 2782 part 10 Method 1001
Compressive strength	ISO 604:2002 Test speed = 1 mm/min
Water absorption	ISO 62:2008 Method 1
	25 mm x 20 mm cylinder (to constant weight)
Oil absorption (light machine)	ISO 175:1999
	25 mm x 20 mm cylinder (to constant weight)
Temperature of deflection under load	ISO 75-2 Method A

3.9.3 The percentage linear shrinkage of cured material is to be measured.

3.9.4 Creep is to be measured according to the following method:

(a) A 25 mm x 20 mm diameter parallel faced cylinder is to be pre-loaded against a steel base at 2,5 N/mm^2 or 3,5 N/mm^2, or at the specified higher loading condition, at ambient temperature for 16 hours.
(b) The temperature is to be increased at the rate of 8°C per hour until the service temperature (60°C or 80°C) is reached.
(c) During this time, the creep of the cylinder is to be measured at 15 minute intervals.
(d) The temperature and loading are to be maintained for a minimum of 100 days measuring the creep at intervals of 24 hours.
(e) A plot of creep in mm (linear scale) against time (log scale), together with full experimental details, is to be provided for review by LR.

3.10 Rudder and pintle bearings

3.10.1 All mechanical properties as required by *Ch 14, 2.12 Rudder and pintle bearings* are to be measured according to suitable National or International Standards.

3.10.2 Frictional properties are to be determined according to a method agreed with LR.

3.11 Sterntube bearings

3.11.1 The requirements for sterntube bearings are as defined in *Ch 14, 2.13 Sterntube bearings*.

Section 4
Plastics pipes and fittings

4.1 Scope

4.1.1 This Section gives the general requirements for plastics pipes and fittings, with or without reinforcement, intended for use in the services listed in the relevant Rules dealing with design and construction. Hoses and mechanical couplings are not covered by these requirements.

4.1.2 Pipes and fittings intended for application in Class I, Class II and Class III systems for which there are Rule requirements, are to be manufactured in accordance with the requirements of *Ch 14, 1 General requirements* and this Section.

4.1.3 As an alternative to *Ch 14, 4.1 Scope 4.1.2*, plastics pipes and fittings which comply with National or proprietary specifications may be accepted, provided that the specifications give reasonable equivalence to the requirements of this Section or, alternatively, are approved for a specific application. The survey and certification are however to be carried out in accordance with the requirements of this Section.

4.2 Design requirements

4.2.1 The requirements for design approval are detailed in the relevant Rules.

4.2.2 The design submission is to include a materials list with confirmation that the materials listed have properties and characteristics conforming with those values used in the design submission. As a minimum, the details given should include the following:

(a) Resin.
(b) Accelerator (type and concentration).
(c) Catalyst or curing agent (type and concentration).
(d) Reinforcement.
(e) Cure/post-cure conditions.
(f) Resin/reinforcement ratio.
(g) Wind angle (or lay-up sequence) and orientation.
(h) Dimensions and tolerances.

This submission is to include similar details for the fittings together with a description of the method of attachment of the fittings to the pipes.

4.2.3 Any alteration of the component materials or manufacturing operations from those used in the design submission will necessitate a completely new submission.

4.2.4 If the piping manufacturer anticipates the possible use of alternative materials, these should be listed in the design submission. Proof that the modified product will meet the specified requirements will be needed prior to its use.

4.3 Manufacture

4.3.1 Plastics pipes and fittings intended for use in Class I, Class II and Class III systems are to be manufactured at facilities approved by LR, using materials approved by LR.

4.3.2 A Manufacturing Specification is to be submitted. This is to contain details of the following:

(a) All constituent materials.
(b) Manufacturing procedures such as lay-up sequence or wind angle, the ratios of curing agent to resin and reinforcement to resin, the laminate thickness, the mandrel dwell time (initial cure) and the cure and post-cure conditions.
(c) Quality control procedures including details and frequency of tests on the incoming materials, tests made during production and on the finished piping.
(d) Acceptance standards and tolerances, including all dimensions.
(e) Procedures for cosmetic repair.
(f) System for traceability of the finished piping to the batches of raw materials.
(g) Method of bonding pipes and fittings.

4.3.3 Details of all raw materials are to be submitted for approval and are to be in accordance with the Manufacturing Specification and the design submission.

4.3.4 All batches of raw materials are to be provided with unique identifications by their manufacturers.

4.3.5 No batch of material is to be used later than its date of expiry.

4.3.6 The piping manufacturer is to ensure that all batches of materials are used sequentially.

4.3.7 The piping manufacturer is to maintain records of the amounts of resin and reinforcement used, in order to ensure that the proportions remain within the limits set in the Manufacturing Specification.

4.3.8 Records are to be kept of the wind angle and/or the orientation of the reinforcement.

4.3.9 The piping manufacturer is to ensure that each item of piping is traceable to the batch or batches of material used in its manufacture. The unique identifications referred to in *Ch 14, 4.3 Manufacture 4.3.4* are to be included on all documents.

4.3.10 The curing oven is to be suitable for the intended purpose and all pyrometric equipment is to be calibrated at least annually and adequate records maintained.

4.3.11 The temperature of the pipe or fitting is to be controlled and recorded by the attachment of suitably placed thermocouples.

4.4 Quality assurance

4.4.1 The piping manufacturer is to have a quality assurance system approved to ISO 9001 or equivalent. This system should ensure that the pipes and fittings are produced with uniform and consistent mechanical and physical properties in accordance with acceptable standards.

4.5 Dimensional tolerances

4.5.1 Dimensions and tolerances are to conform to the Manufacturing Specification.

4.5.2 The wall thicknesses of the pipes are to be measured at intervals around the circumference and along the length in accordance with an appropriate National Standard. The thicknesses are to accord with the Manufacturing Specification.

4.5.3 The responsibility for maintaining the required tolerances and making the necessary measurements rests with the manufacturer. Occasional checking by the Surveyor does not absolve the manufacturer from this responsibility.

4.6 Composition

4.6.1 The composition of the pipes and fittings is to be in accordance with the Manufacturing Specification.

4.6.2 Where alternative materials are used (*see Ch 14, 4.2 Design requirements 4.2.4*), the manufacturer is to demonstrate to the Surveyor's satisfaction, and prior to their introduction, their suitability with respect to the performance of the piping. Otherwise, full testing as specified in *Ch 14, 4.7 Testing* will be required.

4.7 Testing

4.7.1 For thermoplastic pipes, the polymer manufacturer is to make the following measurements on samples taken from each batch:

(a) Melting point.
(b) Melt flow index.
(c) Density.
(d) Filler/pigment content, where applicable.
(e) Tensile stress at yield and break.
(f) Tensile strain at yield and break.

4.7.2 The values obtained are to be certified by the polymer manufacturer.

4.7.3 For reinforced thermoset pipes, the resin manufacturer is to determine, on samples taken from each batch, at least the following:

(a) All resins:
    (i) Viscosity.
    (ii) Gel time.
    (iii) Filler content, where applicable.
(b) Polyester resins:
    (i) Type (orthophthalic, isophthalic, etc.).

(ii) Volatiles content.
(iii) Acid value.

(c) Epoxide resins:

(i) Free epoxide content.

(d) Phenolic resins:

(i) Free phenol content.
(ii) Free formaldehyde content.

4.7.4 The values obtained are to comply with the requirements of the Manufacturing Specification.

4.7.5 Where the resin manufacturer mixes batches, both the original batches and the mixed batch are to be tested in accordance with *Ch 14, 4.7 Testing 4.7.1* as appropriate. The mixed batch is then to be given a unique batch number.

4.7.6 The polymer or resin manufacturer is to demonstrate that each batch of polymer or resin satisfies the requirement for temperature of deflection under load and this is not to be less than 80°C.

4.7.7 These measurements should be repeated on each batch by the piping manufacturer. Where this is not done, LR may require that the tests be made on a random basis by an independent laboratory.

4.7.8 The piping manufacturer is to confirm, by means of tests on at least one batch in twenty, that the temperature of deflection under load exceeds the specified minimum under manufacturing conditions.

4.7.9 Where reinforcements are used, at least the following are to be recorded, where applicable:

(a) Tex of yarn(s) or roving(s).
(b) Ends per 100 mm in all reinforcement orientations.
(c) Weight per square metre.
(d) Binder/size content.
(e) Stitch type and count.
(f) Type of fibre used.
(g) Surface treatment and/or finish.

4.7.10 All items in *Ch 14, 4.7 Testing 4.7.9* are to comply with the Manufacturing Specification.

4.7.11 The piping manufacturer is to maintain accurate records of resin and glass usage and is to calculate the resin/glass ratio on an ongoing basis.

4.7.12 During manufacture of the piping, apart from the requirements of *Ch 14, 4.7 Testing 4.7.5*, *Ch 14, 4.7 Testing 4.7.6* and *Ch 14, 4.7 Testing 4.7.8*, tests are to be carried out on the constituents and final product in accordance with *Table 14.4.1 Testing during manufacture of pipes*.

Table 14.4.1 Testing during manufacture of pipes

Component/ operation	Characteristic	Rate of testing
Resin/curing agent/catalyst	Gel time Rate of consumption	Two per shift Continuous
Reinforcement	Quality Wind angle Rate of consumption	Continuous Continuous Continuous
Resin/ reinforcement	Ratio	Continuous

Pipe	Post-cure:	
	temperature of the pipe in oven	Continuous
	Cure level	At least eight per length
	Dimensions	Each length
	Hydraulic pressure test	Each length
	Electrical resistance	Each length (*see* Note)
	Hydraulic bursting test	At Surveyor's discretion
	Axial strength	At Surveyor's discretion
Note Measurements of electrical resistance are only required on piping where the operating conditions given in *Pt 5, Ch 12, 5.2 Design and performance criteria 5.2.4* of the *Rules and Regulations for the Classification of Ships* apply.		

4.7.13 The standards of acceptance are those listed in the Manufacturing Specification approved by LR.

4.7.14 At the Surveyor's discretion, sections of pipe are to be subjected to hydraulic bursting tests and/or measurements of axial strength.

4.7.15 If the batch of resin or polymer, or the curing agent, or their ratio is changed during manufacture of a batch of pipes, at least two additional measurements of the gel time are to be carried out during each shift.

4.8 Visual examination

4.8.1 All pipes and fittings are to be visually examined and are to be free from surface defects and blemishes.

4.8.2 The pipes are to be reasonably straight and the cut ends are to be square to the axis of the pipe.

4.9 Hydraulic test

4.9.1 Each length of pipe is to be tested at a hydrostatic pressure not less than 1,5 times the rated pressure of the pipe.

4.9.2 The test pressure is to be maintained for sufficient time to permit proof and inspection. Unless otherwise agreed, the manufacturer's certificate of satisfactory hydraulic test, endorsed by the Surveyor, will be accepted.

4.10 Repair procedure

4.10.1 Repairs are not allowed, with the exception of minor cosmetic blemishes as detailed in *Ch 14, 1.10 Rectification of defective material 1.10.1*.

4.10.2 A repair procedure for these minor blemishes is to be included in the Manufacturing Specification.

4.11 Identification

4.11.1 All piping is to be identified in such a manner that traceability to all the component materials used in its manufacture is ensured. The Surveyor is to be given full facilities for so tracing the material when required.

4.11.2 Pipes and fittings are to be permanently marked by the manufacturer by moulding, hot stamping or by any other suitable method, such as printing, in accordance with *Ch 14, 1.11 Identification of products and base materials*. The markings are to include:

(a) Identification number, *see Ch 14, 4.11 Identification 4.11.1*.
(b) LR or Lloyd's Register, and the abbreviated name of LR's local office.
(c) Manufacturer's name or trademark.
(d) Pressure rating.
(e) Design standard.
(f) Material system with which the piping is made.
(g) Maximum service temperature.

4.12 Certification

4.12.1 The manufacturer is to provide the Surveyor with copies of the test certificates or shipping statements for all material which has been accepted.

4.12.2 Each test certificate is to contain the following particulars:

(a) Purchaser's name and order number.
(b) If known, the contract number for which the piping is intended.
(c) Address to which piping is despatched.
(d) Type and specification of material.
(e) Description and dimensions.
(f) Identification number, *see Ch 14, 4.11 Identification 4.11.1*.
(g) Test results.

■ *Section 5*
Control of material quality for composite construction

5.1 Scope

5.1.1 This Section gives the general requirements for control of material quality when used in the construction of composite craft.

5.1.2 For composite craft built under the Rules, the survey of materials is to be conducted in accordance with the requirements of *Ch 14, 1 General requirements* and this Section.

5.2 Design submission

5.2.1 The requirements for design submission are detailed in the appropriate Part of the Rules which includes full information on composite materials.

5.3 Construction

5.3.1 All constructions are to be carried out using materials approved or accepted by LR.

5.3.2 All materials are to be in accordance with the approved construction documentation.

5.3.3 All batches of materials are to be provided with unique identifications by their manufacturers. Components are to be similarly identified.

5.3.4 No batch of material is to be used later than its date of expiry.

5.3.5 The Builder is to ensure that all batches of materials are used systematically and sequentially.

5.3.6 The Builder is to maintain, on a continuous basis, records of the amounts of resin and reinforcement used, in order to ensure that the proportions remain within the limits set in the construction documentation.

5.3.7 Records are to be kept of the sequence and orientation of the reinforcements.

5.3.8 The Builder is to ensure that each section of the construction is traceable to the batch or batches of material used. The unique identifications required under *Ch 14, 1.11 Identification of products and base materials 1.11.1* are to be included on all relevant quality control documentation.

5.3.9 Any curing system used is to be demonstrated as suitable for the intended purpose and all pyrometric equipment is to be calibrated at least annually and adequate records maintained.

5.3.10 The post-curing temperature is to be controlled and recorded by the attachment of suitably placed thermocouples.

5.4 Quality assurance

5.4.1 Where the Builder has a quality assurance system, this is to include the requirements of this Section.

5.5 Dimensional tolerances

5.5.1 Dimensions and tolerances are to conform to the approved construction documentation.

5.5.2 The thicknesses of the laminates are, in general, to be measured at not less than ten points, evenly distributed across the surface. In the case of large sections, at least ten evenly distributed measurements are to be taken in bands across the width at maximum spacing of two metres along the length.

5.5.3 The responsibility for maintaining the required tolerances and making the necessary measurements rests with the Builder. Monitoring and random checking by the Surveyor does not absolve the Builder from this responsibility.

5.5.4 Where ultrasonic thickness gauges are used, these are to be calibrated against an identical laminate (of measured thickness) to that on which the thickness measurement is to be carried out. If suitable pieces are not available from the construction, then a small sample of identical lay-up is to be prepared.

5.6 Material composition

5.6.1 The materials, prefabricated sections or components used are to be in accordance with the approved construction documentation.

5.6.2 Where alternative materials are used, these are to be of approved or accepted types and the manufacturer is to demonstrate to the Surveyor's satisfaction, prior to their introduction, their suitability with respect to performance, otherwise full testing as appropriate will be required.

5.7 Material testing

5.7.1 Where so required, the material manufacturer is to provide the purchaser with certificates of conformity for each batch of material supplied, indicating the relevant values specified in *Ch 14, 5.7 Material testing 5.7.4*. These values are to comply with those specified by the approved construction documentation.

5.7.2 Where the Builders do not conduct verification testing of the information indicated in *Ch 14, 5.7 Material testing 5.7.4*, they are to ensure that copies of all certificates of conformity (which must indicate the actual tested values) are obtained for all batches of materials received, and maintain accurate records. The Surveyor may at any time select a sample of a material for testing by an independent, where applicable, source and should such tests result in the material failing to meet the specification, then that batch will be rejected.

5.7.3 The following tests are to be carried out, where applicable, on receipt of any material:

(a) The consignment is to be divided into its respective batches and each batch is to be labelled accordingly.
(b) Each batch is to be visually examined for conformity with the batch number, visual quality and date of expiry.
(c) Each batch is to be separately labelled and stored separately.
(d) Each unit, within the batch, is to be labelled with the batch number.
(e) Records are to be maintained of the above and these are to be cross-referenced with the certificate of conformity for the material and/or the Builder's own test results.

5.7.4 For thermosetting resins, reinforced or otherwise, the resin manufacturer is to have determined, on samples taken from each batch, at least the following:

(a) All resins:
    (i) Viscosity.
    (ii) Gel time.
    (iii) Filler content, where applicable.
(b) Polyester and vinylester resins:
    (i) Type (orthophthalic, isophthalic, etc.).
    (ii) Volatiles content.
    (iii) Acid value.
(c) Epoxide resins:
    (i) Free epoxide content.
(d) Phenolic resins:
    (i) Free phenol content.
    (ii) Free formaldehyde content.

5.7.5 For thermoplastics, the polymer manufacturer is to have made the following measurements on samples taken from each batch:

(a) Melting point.
(b) Melt flow index.
(c) Density.
(d) Filler/pigment content, where applicable.
(e) Tensile stress at yield and break.
(f) Tensile strain at yield and break.

5.7.6 Where the resin or polymer manufacturer mixes batches, both the original batches and the mixed batch are to be tested in accordance with *Ch 14, 5.7 Material testing 5.7.4* or *Ch 14, 5.7 Material testing 5.7.5* as appropriate. The mixed batch is then to be given a unique batch number.

5.7.7 For reinforcements, the material manufacturer is to have recorded, where applicable, the following for each batch of material:

(a) Tex of yarn(s) or roving(s).
(b) Ends per 100 mm in all reinforcement orientations.
(c) Weight per square metre.
(d) Binder/size content.
(e) Stitch type and count.
(f) Type of fibre used.
(g) Surface treatment and/or finish.

5.7.8 For core materials, the following properties are to be recorded by the manufacturer for each batch:

(a) Type of material.
(b) Density.
(c) Description (block, scrim mounted, grooved).
(d) Thickness and tolerance.
(e) Sheet/block dimensions.
(f) Surface treatment.

Together with the following mechanical properties:

In the case of rigid foams:

(a) Compressive strength (stress at maximum load) and modulus of elasticity.
(b) Core shear strength.

In the case of end-grain balsa:

(a) Tensile strength (stress at maximum load).
(b) Compressive strength (stress at maximum load) and modulus of elasticity.

5.7.9 During construction, tests are to be carried out on the constituents and final product in accordance with *Table 14.5.1 Tests during construction*.

5.7.10 The standards of acceptance for testing are those listed in the material manufacturer's specification, approved construction documentation or agreed quality control procedures as applicable.

5.7.11 Laminate fibre content is to be determined at the request of the Surveyor, in particular where the thickness measured does not correlate with the specified fibre content, by weight. This will, in general, result in additional reinforcement being required.

5.7.12 If the batch of resin or polymer, or the curing agent, or their ratio is changed, at least two additional measurements of the gel time are to be carried out during each shift.

Table 14.5.1 Tests during construction

Component/operation	Characteristic	Rate of testing
Resin/curing agent/catalyst	Gel time	Two per shift
	Rate of consumption	Continuous
Reinforcement	Quality	Continuous

	Orientation Rate of consumption	Continuous Continuous
Resin/reinforcement	Ratio	Continuous
Construction	Temperature during cure/post cure	Continuous
	Dimensions	Continuous against approved construction documentation
	Cure level (Barcol) against resin manufacturer's specification	At least one per square metre
	Laminate thickness	Continuous against material usage and approved construction documentation (*see also Ch 14, 5.5 Dimensional tolerances 5.5.2*
	Laminate fibre content	At the Surveyor's request (*see Ch 14, 5.7 Material testing 5.7.11*)

5.8 Visual examination

5.8.1 All constructional mouldings and any components are to be visually examined and are to be free from surface defects and blemishes.

5.9 Repair procedure

5.9.1 Repairs of minor cosmetic blemishes are permitted providing that these are brought to the attention of the Surveyor.

5.9.2 A repair procedure for these minor blemishes is to be included in the agreed quality control procedures.

5.9.3 Structural repairs are subject to individual consideration and full written details must be approved by the plan approval office prior to introduction.

5.10 Material identification

5.10.1 Records of the construction are to be kept in such a manner that traceability of all the component materials used is ensured. The Surveyor is to be given full facilities for tracing the material's origin when required.

5.10.2 Small representative samples of each batch of material are to be retained, these being suitably labelled to ensure tracebility.

5.10.3 When so requested by the Surveyor, the Builder is to provide copies of all test data and/or manufacturers' certificates of conformity appertaining to any material used.

5.11 Minimum tested requirements for material approval

5.11.1 This Section provides the minimum property values required of a material for approval or acceptance by LR and are applicable to materials cured under ambient conditions.

5.11.2 **Gel coat resins**. When the cast resin is tested according to the requirements of *Ch 14, 2.3 Thermosetting resins*, *Table 14.5.2 Gel coat resins, minimum property values* gives the minimum values for the respective properties.

Table 14.5.2 Gel coat resins, minimum property values

Properties	Minimum value
Tensile strength (stress at maximum load)	40 N/mm^2
Tensile stress at break	40 N/mm^2
Tensile strain at maximum load	2,5%
Modulus of elasticity in tension	As measured
Flexural strength (stress at maximum load)	80 N/mm^2
Modulus of elasticity in flexure	As measured

Barcol hardness	As measured at full cure
Water absorption	70 mg (max)

5.11.3 **Laminating resins**. When tested according to the requirements of *Ch 14, 2.3 Thermosetting resins* and *Ch 14, 2.4 Reinforcements*, *Table 14.5.3 Laminating resins, minimum property values* and *Table 14.5.4 Laminating resins, minimum values for properties for CSM laminate at 0,3 glass fraction by weight* give the minimum properties for the cast resin and chopped strand mat laminate respectively.

Table 14.5.3 Laminating resins, minimum property values

Properties	Minimum value
Tensile strength (stress at maximum load)	40 N/mm^2
Tensile stress at break	40 N/mm^2
Tensile strain at maximum load	2,0%
Modulus of elasticity in tension	As measured
Barcol hardness	As measured at full cure
Temperature of deflection under load	55°C
Note These minimum value are for the recommended glass content by weight of 0,3.	

Table 14.5.4 Laminating resins, minimum values for properties for CSM laminate at 0,3 glass fraction by weight

Properties	Minimum value
Tensile strength (stress at maximum load)	90 N/mm^2
Secant modulus at 0,25% and 0,5% strain respectively	6,9 kN/mm^2
Compressive strength (stress at maximum load)	125 N/mm^2
Compressive modulus	6,4 kN/mm^2
Flexural strength (stress at maximum load)	160 N/mm^2
Modulus of elasticity in flexure	5,7 kN/mm^2
Apparent interlaminar shear	18 N/mm^2
strength (*see* Note)	
Fibre content	As measured (0,3)
Water absorption	70 mg (max)
Note Applicable only to the special test for environmental control resins.	

5.11.4 When tested to the requirements of *Ch 14, 2.4 Reinforcements* for reinforcements, *Table 14.5.5 Laminates, minimum property requirements* gives the minimum properties for laminates.

Table 14.5.5 Laminates, minimum property requirements

Material type	Property	Value
Chopped strand mat	Tensile strength (stress at maximum load) (N/mm^2)	$200G_C + 30$
	Modulus of elasticity in tension (kN/mm^2)	$15G_C + 2,4$
Bi-directional reinforcement	Tensile strength (stress at maximum load) (N/mm^2)	$400G_C - 10$
	Modulus of elasticity in tension (kN/mm^2)	$30G_C -0,5$
Uni-directional reinforcement	Tensile strength (stress at maximum load) (N/mm^2)	$1800G_C^2 - 1400G_C + 510$
	Modulus of elasticity in tension (kN/mm^2)	$130G_C^2 - 114G_C + 39$
Chopped strand mat	Flexural (stress at maximum load) (N/mm^2)	$502G_C^2 + 114,6$
	Modulus of elasticity in flexure (kN/mm^2)	$33,4G_C^2 + 2,7$
All	Flexural strength (stress at maximum load) (N/mm^2)	$502G_C^2 + 106,8$
	Modulus of elasticity in flexure (kN/mm^2)	$33,4G_C^2 + 2,2$
	Compressive strength (stress at maximum load) (N/mm^2)	$150G_C + 72$
	Compressive modulus (kN/mm^2)	$40G_C - 6$
	Interlaminar shear strength (N/mm^2)	$22 - 13,5G_C$ (min 15)
	Water absorption (mg)	70 (maximum)
	Glass content (% by weight)	As measured

Note 1. After water immersion, the values shall be a minimum of 75% of the above.

Note 2. Where materials have reinforcement in more than two directions, the requirement will be subject to individual consideration dependent on the construction.

Note 3. G_C = glass fraction by weight.

5.11.5 Alternatively, materials may be approved by use of the actual tested values whereby the approval value shall equal the mean of the tested values minus twice the standard deviation of a minimum of five tested values.

5.12 Closed cell foams for core construction based on PVC or polyurethane

5.12.1 *Table 14.5.6 Minimum characteristics and mechanical properties of rigid expanded foams at 20°C* gives minimum values for closed cell forms for core construction based on PVC or polyurethane.

Table 14.5.6 Minimum characteristics and mechanical properties of rigid expanded foams at 20°C

Material	Apparent density kg/m^3	Strength (stress at maximum load) (N/mm^2)			Modulus of elasticity (N/mm^2)	
		Tensile	Compressive	Shear	Compressive	Shear
Polyurethane	96	0,85	0,60	0,50	17,20	8,50
Polyvinylchloride	60					

5.12.2 Other types of foam will be subjected to individual consideration. A minimum core shear strength of 0,5 N/mm^2 is to be achieved.

5.13 End-grain balsa

5.13.1 *Table 14.5.7 Minimum characteristics and mechanical properties of end-grain balsa* gives the minimum property requirement for end-grain balsa.

Table 14.5.7 Minimum characteristics and mechanical properties of end-grain balsa

Apparent density (kg/m^3)	Strength (stress at maximum load) (N/mm^2)					Compressive modulus of elasticity (N/mm^2)		Shear modulus of elasticity (N/mm^2)
	Compressive		Tensile		Shear			
	Direction of stress					Direction of stress		
	Parallel to grain	Perpendicular to grain	Parallel to grain	Perpendicular to grain		Parallel to grain	Perpendicular to grain	
96	5,0	0,35	9,00	0,44	1,10	2300	35,2	105
144	10,6	0,57	14,6	0,70	1,64	3900	67,8	129
176	12,8	0,68	20,5	0,80	2,00	5300	89,6	145

5.14 Synthetic chocking compounds

5.14.1 After 1000 hours the chocking resin must be stabilised and maximum creep is to be less than or equal to 0,2 per cent.

5.14.2 Compliance with *Ch 14, 5.14 Synthetic chocking compounds 5.14.1* is to be demonstrated at the time of chocking compound approval for a specified cure/post cure schedule. The Izod, barcol, compression, and water and oil absorption are additionally to be determined for the creep tested cure/post cure schedule.

5.14.3 Confirmation of creep, barcol and compression will be required for cure/post cure conditions which differ from those shown on the product approval certificate.

5.15 Other materials

5.15.1 All other materials will be subject to special consideration.

■ *Section 1* General Requirements

1.1 Scope

1.1.1 This Chapter specifies the requirements for the corrosion protection of ships and other marine structures. In general, suitable protective systems may include coatings, corrosion resistant materials, cathodic protection, corrosion allowances or other approved methods, either individually or in combination. Corrosion protection systems should be selected with consideration for the design life of the structure, and the in-service inspection and maintenance regimes.

1.1.2 The materials and processes described in this Chapter are to be considered in accordance with the requirements of the relevant design and construction Rules, as well as the ShipRight Procedure *Anti-Corrosion System Notation*. Where applicable, the requirements of current statutory legislation must be satisfied.

■ *Section 2* Coatings

2.1 General

2.1.1 The following plans and information regarding corrosion protection by the use of coatings are to be agreed between the shipyard and owner prior to construction, and, where required by subsequent sections, submitted to Class for review:

(a) A copy of the Lloyd’s Register approval certificate for pre-fabrication primer (shop-primer).
(b) Details of the coating system. This is to include the paint specification with regard to:
  (i) The identity and generic type of the coating, and confirmation by the manufacturer of its suitability for the intended environment;
  (ii) The methods used to prepare the surface before the coating is applied, and the standards to be achieved, with reference to shipyard standards, or National or International Standards;
  (iii) The method of application of the coating in each area; and
  (iv) The number of coats to be applied, with the nominal total dry film thickness.
(c) Details of the areas to be coated.

2.1.2 Paints or other coatings are to be confirmed as being suitable for their intended purpose in the locations where they are to be used. In areas not covered by the Regulations identified in the following Sections, this shall be demonstrated by the submission of the paint manufacturer’s technical data sheet, together with appropriate in-service experience.

2.1.3 Coatings used in cargo oil tanks, cargo tank deck areas, pump rooms, cofferdams or any other area where flammable vapours may accumulate shall be coated using suitable coating systems. If the selected coatings for these spaces contain aluminium, it shall be present at less than 10 per cent by weight in the dry film.

2.1.4 Coatings utilised in areas such as accommodation or defined escape routes are required to comply with the appropriate Sections of the following SOLAS Regulations:

(a) Areas defined as requiring low flame spread coatings shall be treated in accordance with SOLAS II-2, Regulation 5.
(b) Areas defined as requiring low smoke and toxicity emission coatings shall be treated in accordance with SOLAS II-2, Regulation 6.

2.1.5 Coating manufacturers shall comply with the requirements of *Ch 1, 2.1 Approval and survey requirements – General 2.1.5* regarding control of the manufacturing process.

2.1.6 The top coat of coating systems used in spaces subject to scheduled inspection should be light in colour to assist the Surveyor.

2.2 Surface preparation

2.2.1 Coatings are to be applied in accordance with the manufacturer's recommendations, to surfaces prepared in accordance with the agreed coating application specification.

2.2.2 The surface treatment prior to coating application should be performed in accordance with the manufacturer's recommendations, unless a mandatory minimum standard has been established for specified areas, such as in Sections *Ch 15, 2.4 Seawater ballast tank coatings* and *Ch 15, 2.5 Cargo oil tank coatings* below.

2.2.3 Dust and surface contamination, such as oil or salt deposits, is to be removed, as far as is practicable, from the surface prior to the application of any paint. The cleanliness of the surface should be measured using appropriate shipyard, National or International standard methods, with the following properties assessed:

(a) Residual salt levels.
(b) Oil contamination.
(c) Dust or other particulates.

2.2.4 Appropriate methods shall be used to remove, as far as practicable, surface contamination detected when assessing the surfaces. Selection of these methods shall consider the location of the surface to be cleaned, any applicable standards and any local environmental legislation.

2.3 Pre-fabrication primers (Shop primers)

2.3.1 Where a pre-fabrication primer is used to coat steel after surface preparation and prior to fabrication, the composition of the coating is to be such that it will have no significant deleterious effect on subsequent welding work, and it is to be compatible with the coatings subsequently applied over it.

2.3.2 For Lloyd's Register classed vessels and structures the pre-fabrication primer shall be of an approved type. A list of pre-fabrication primers currently approved by LR is available on Lloyd's Register's Class Direct website, accessible at http://www.lr.org.

2.3.3 The full approval procedure is detailed in MQPS Book P, Procedure 19-5.

2.4 Seawater ballast tank coatings

2.4.1 For ships that are required to comply with IMO *Resolution MSC.215(82) - Performance Standard for Protective Coatings for Dedicated Seawater Ballast Tanks in all Types of Ships and Double-Side Skin Spaces of Bulk Carriers - (Adopted on 8 December 2006)*, all dedicated seawater ballast tanks for all ship types and double-side skin spaces of bulk carriers are to have approved coating systems applied in accordance with the ShipRight Procedure *Anti-Corrosion Systems Notation*.

2.4.2 The procedure for coating system type approval is detailed in MQPS Book P, Procedure 19-3. A list of PSPC-compliant seawater ballast tank coating systems currently type approved by LR is available on Lloyd's Register's Class Direct website.

2.4.3 The compliance of the vessel with the PSPC requirements is demonstrated by the formal acceptance of the Coating Technical File (CTF) and the issue of the vessel's SOLAS certificate. A copy of the accepted CTF shall be retained on the vessel. The appropriate Class notations will be assigned in accordance with the ShipRight Procedure *Anti-Corrosion System Notation*.

2.4.4 The CTF shall record all of the mandatory information required by the PSPC, including the paint schedule, primary surface preparation, pre-fabrication priming, secondary surface preparation, assessment of the surface condition, coating application, repairs and evidence of the resolution of any non-compliances. This data is to be recorded by a designated, appropriately qualified coatings inspector assigned by the ship builder.

2.4.5 Maintenance of PSPC-compliant coatings in accordance with the CTF is mandatory.

2.4.6 For ships that are not required to comply with IMO *Resolution MSC.215(82) - Performance Standard for Protective Coatings for Dedicated Seawater Ballast Tanks in all Types of Ships and Double-Side Skin Spaces of Bulk Carriers - (Adopted on 8 December 2006)*, all seawater ballast spaces having boundaries formed by the hull envelope are to have a corrosion protection coating applied, *see* ShipRight Procedure *Protective Coatings in Water Ballast Tanks (PCWBT)*.

2.4.7 Where requested, a Descriptive Note **PCWBT** will be entered in column six of the *Register Book* to indicate that all seawater ballast spaces having boundaries formed by the hull envelope have a corrosion protection coating applied, and that the

coating remains efficient and is maintained in good condition. If the coatings have broken down, particularly at more critical areas, and no effort is being made to maintain the coatings, then this note will be placed in parentheses, i.e. **(PCWBT)**. In either case, the date of the last survey will be placed in parentheses after the note.

2.5 Cargo oil tank coatings

2.5.1 For ships that are required to comply with IMO *Resolution MSC.288(87) – Performance Standard for Protective Coatings for Cargo Oil Tanks of Crude Oil Tankers – (Adopted on 14 May 2010)*, all cargo oil tanks are to have type approved coating systems applied in accordance with ShipRight Procedure *Anti-Corrosion System Notation*. Owners may request to receive the optional notation **ShipRight ACS(C)**.

2.5.2 The procedure for coating system type approval is detailed in MQPS Book P, Procedure 19-4. A list of PSPC-COT compliant cargo oil tank coating systems currently type approved by LR is available on Lloyd's Register's Class Direct website.

2.5.3 Sections*Ch 15, 2.4 Seawater ballast tank coatings 2.4.4*, *Ch 15, 2.4 Seawater ballast tank coatings 2.4.5* and *Ch 15, 2.4 Seawater ballast tank coatings 2.4.6* above apply.

2.5.4 Where the vessel's Owner has not requested to receive the **ShipRight ACS(C)** notation, compliance with the PSPC-COT Regulation is demonstrated by the formal acceptance of the Coating Technical File and the issue of the vessel's Oil Tanker Safety Certificate.

2.6 Void space coatings

2.6.1 Ships within the scope of IMO *Resolution MSC.244(83) - Adoption of Performance Standard for Protective Coatings for Void Spaces on Bulk Carriers and Oil Tankers - (Adopted on 5 October 2007)* may, if requested by the Owner, receive an optional notation in accordance with the ShipRight Procedure *Anti-Corrosion System Notation*.

2.6.2 Void spaces on ships should, if possible, be coated in accordance with IMO *Resolution MSC.244(83) - Adoption of Performance Standard for Protective Coatings for Void Spaces on Bulk Carriers and Oil Tankers - (Adopted on 5 October 2007)*, which is not mandatory. Where an alternative to these guidelines is used the coating system selected shall be suitable for the service environment, and applied in accordance with the manufacturer's instructions.

2.7 Bulk carrier cargo hold coatings

2.7.1 The cargo hold spaces of bulk carriers shall be protected by a suitable corrosion protection coating. The coating system selected shall be suitable for the intended cargoes and applied in accordance with the manufacturer's instructions.

2.7.2 All internal and external surfaces of hatch coamings and hatch covers, and all internal surfaces of the cargo holds, excluding the flat tank top areas and the hopper tank sloping plating more than approximately 300 mm below the side shell frame and brackets, shall be coated.

2.8 Other internal tanks

2.8.1 Other internal tanks not covered by the above may include those intended for the storage of, for example: black water; grey water; potable or made water, permanent ballast tanks, fuel tanks, etc.

2.8.2 Internal tanks and other compartments may require corrosion protection where the intended contents may cause or promote corrosion. Acceptable protective measures may include suitable coatings, cathodic protection or corrosion inhibitors, either individually, or in combination.

2.8.3 Selection of any coating system for such spaces shall be based upon the intended contents, the position of the space within the hull, the expected frequency of use in service and the coating manufacturer's recommendations.

2.8.4 Some internal spaces are subject to Flag State or other local regulations regarding the coatings and other corrosion prevention systems that may be used. The selected coating system shall be fully compliant with all relevant legislation and be capable of protecting the tank from corrosion in applications where the use of sacrificial anodes is prohibited, such as in potable water tanks.

2.9 Coatings for external hulls

2.9.1 External hulls are to be protected from corrosion by the use of appropriate anti-corrosive measures, which may include the application of suitable coating systems to all external surfaces.

2.9.2 Coatings used for corrosion prevention of exterior hulls should be confirmed as suitable for this application by the manufacturer, whose recommendations regarding surface preparation and coating application should be followed. Compatibility of the coating with other anti-corrosive measures should be confirmed by the coating manufacturer.

2.9.3 High resistance paints (HRP) shall be used on the underwater hull of vessels applying for or in possession of the in-water survey notation ***IWS**. High resistance paints shall be of a hard, convertible type, such as an epoxy, polyurethane or equivalent, and shall be applied in accordance with the manufacturer's recommendations.

2.9.4 Vessels applying for the ***IWS** notation must submit the details of the coatings selected for review, including the manufacturer's technical data sheets, the number of coats and the total dry film thicknesses applied.

2.9.5 Coatings which have been certified by LR as being either PSPC-compliant seawater ballast tank coatings or recognised Corrosion Control Coatings (CCC) are automatically acceptable as high-resistance paints. Any such certification should be submitted when requesting the in-water survey Notation as above.

2.9.6 The procedure of LR recognition for Corrosion Control Coatings is detailed in MQPS Book P, Procedure 19-7. A list of corrosion control coatings currently recognised by LR is available on Lloyd's Register's Class Direct website.

2.10 Anti-fouling coatings

2.10.1 Coatings used on the hulls of LR classed vessels shall be recognised by LR as complying with the IMO Convention on the Control of Harmful Anti-fouling Systems on Ships.

2.10.2 Compliance of a coating shall be demonstrated prior to use by the issue of a certificate of recognition, or alternatively by the sampling of the coating during or immediately after application. Coating samples shall be tested for their organotin content and confirmed as being compliant before the vessel is issued with its AFS convention certificate.

2.10.3 The procedure for achieving LR recognition is detailed in MQPS Book P, Procedure 19-6. A list of anti-fouling coatings currently recognised by LR is available on Lloyd's Register's Class Direct website.

2.11 Cargo tanks of product carriers or mixed-use tankers

2.11.1 The cargo tanks of tankers engaged in the carriage of refined products or mixed product/crude oil usage should be protected from corrosion by the application of corrosion resistant alloys, or alternatively by the application of suitable coatings or other corrosion prevention systems.

2.11.2 Any coating used in such environments should be of a type recommended by the manufacturer for that use, and applied according to their recommendations. Proof of compatibility of the coating with the intended cargoes shall be provided by the coating manufacturer.

2.12 Coating maintenance and repairs

2.12.1 The regular inspection, maintenance and, where necessary, repair of coatings are essential to preserve their anti-corrosive performance during the life of the vessel.

2.12.2 Where deterioration in the quality of a coating is identified, it should be addressed immediately, and preferably restored to the original condition.

2.13 Ice coatings

2.13.1 Low friction surface coatings for use on the ice belt of Ice Class vessels may be recognised for this application by LR. Ice Class vessels using recognised coatings will receive a 1 mm reduction in the abrasion and corrosion allowance when calculating the required shell thickness in the ice belt.

2.13.2 A combination of laboratory tests and in-service inspections by LR Surveyors of vessels that have been operated in ice conditions for at least two winters is required for full recognition.

2.13.3 Laboratory tests shall include assessments of the coating's resistance to abrasion, impact resistance, strength of adhesion to the substrate and flexibility, in addition to conventional corrosion resistance tests.

2.13.4 A list of ice coatings currently recognised by LR is available on Lloyd's Register's Class Direct website.

Section 3
Corrosion Resistant Steels

3.1 Performance standard and definition

3.1.1 IMO *Resolution MSC.289(87) – Performance Standard for Alternative Means of Corrosion Protection for Cargo Oil Tanks of Crude Oil Tankers – (Adopted on 14 May 2010)* defines minimum standards for the means of corrosion protection by the use of approved corrosion resistant steel in cargo oil tanks during the construction of crude oil tankers.

3.1.2 Corrosion resistant steel is steel whose corrosion resistance performance in the bottom or top of the internal cargo oil tank is tested and approved to satisfy the requirements in the IMO Performance Standard in addition to other relevant requirements for ship steel, structure strength and construction.

3.2 Corrosion resistant steel approval

3.2.1 The compliance of the corrosion resistant steel with the IMO Performance Standard shall be confirmed on the steel manufacturer's Approval certificate. The full approval procedure for corrosion resistant steel manufacturers and for the steel products involved is contained in MQPS Book C, Procedure 3-3.

3.2.2 The compliance of the vessel with IMO Performance Standard is indicated by the acceptance of the Technical File (TF) by the Flag State or their Recognised Organisation (RO), the issue of the vessel's SOLAS certificate and, if requested, the assignment of the appropriate notations by the Class Society. The TF must be kept on board and maintained throughout the life of the vessel.

3.2.3 The TF shall record all of the data required by IMO Performance Standard, including a copy of the Works Approval Certificate, technical data (approved welding methods, welding consumables and repair procedures) and records of the application, including the applied actual space and area of each compartment and the applied product and its thickness.

3.3 Certification

3.3.1 For certification requirements, *see Ch 3, 1.3 Corrosion resistant steels for cargo oil tanks of crude oil tankers 1.3.8*.

Section 4
Cathodic Protection (CP)

4.1 General principles

4.1.1 Where the design requires application of cathodic protection systems, either by impressed current or sacrificial means, this Section gives guidance on satisfying this requirement.

4.1.2 The type of cathodic protection of the structure required is to be considered in terms of the following zones:

(a) Submerged zone. That part of the hull below the maximum design operating draught.
(b) Splash zone. That part of the hull above the submerged zone and subject to wet and dry conditions.
(c) Atmospheric zone. That part of the hull above the splash zone.

Cathodic protection inside tanks is considered separately (*see* Section *Ch 15, 4.8 Cathodic protection in tanks*).

4.1.3 The cathodic protection system for the submerged areas should be capable of polarising the steelwork to a sufficient level in order to minimise corrosion. This may be achieved using an impressed current system, sacrificial anodes or a combination of both.

4.1.4 All parts of the submerged structure should be electrically continuous, and where considered necessary, appropriate bonding devices and straps should be fitted across such items as propeller shafts, thrusters, stabilisers and rudders, pipe work, etc. Where bonding straps are not fitted then a supplementary cathodic protection system should be considered. The influence of any connecting structures, such as docking structures, on the efficiency of the cathodic protection system should be evaluated.

4.1.5 The cathodic protection system is to be capable of polarising the steel structure to potentials measured with respect to a silver/silver chloride/seawater (Ag/AgCl) reference electrode to within the range -0,80 to -1,20 volts for open seawater conditions. An average potential range from -0,90 to -0,95 volts vs. Ag/AgCl may be considered ideal. The electrode potential for steels which have surfaces operating above 25°C should be 1 mV (0,001 V) more negative for each degree above 25°C.

4.1.6 Potentials more negative than -1,20 volts vs. Ag/AgCl must be avoided in order to minimise any damage to the coating system.

4.1.7 In applications where high strength steels (tensile strengths in excess of 700 N/mm^2) are used in the submerged zone, potentials should be limited to -0,95 volts vs. Ag/AgCl in order to reduce the possibility of hydrogen embrittlement.

4.1.8 High strength fastening materials should be avoided due to the possible effects of hydrogen absorption. If the use of high strength fasteners is unavoidable, then the hardness of such bolting materials should be limited to a maximum of 300 HV.

4.1.9 When selecting protection systems the following items are normally considered:

(a) A surface area breakdown for all areas to be protected, including appendages.
(b) The assumed resistivity of the seawater.
(c) All current densities used for design purposes.
(d) The type and location of any reference electrodes and their methods of attachment.
(e) Full details of any coatings used and the areas to which they are to be applied.
(f) Details of the shaft grounding.
(g) The electrical bonding.

4.2 CP systems for the submerged zones of ships

4.2.1 Where the design specifies cathodic protection, the typical requirements of the hull and hull appendages and openings are given in *Table 15.4.1 Typical corrosion protection requirements for the hull steelwork*.

Table 15.4.1 Typical corrosion protection requirements for the hull steelwork

Corrosion protection required and area		
Zone	Structural steelwork	Method of protection required
Submerged zone	Main hull	Coatings, or coatings in combination with cathodic protection
Splash zone	Main hull	Coatings
Atmospheric zone	All structure above the splash zone	Coatings only

4.3 Impressed Current Cathodic Protection (ICCP)

4.3.1 When designing an ICCP system, the following items are to be considered in addition to those identified in *Ch 15, 4.1 General principles 4.1.9*:

(a) The anode composition and, where applicable, the thickness of the plated surface together with consumption and life data.
(b) Anode resistance, limiting potential and current output.
(c) System maximum operating voltage.
(d) Details of the anode and reference electrode cofferdam construction, including the specification of the steel used and welding details, and the standards and specifications which are applicable.
(e) Size, shape and composition of the dielectric shields.
(f) Diagram of the wiring system used for the impressed current and monitoring systems including details of cable sizes, junction boxes, joints (if any), type of insulation and normal working current in circuits, as well as the capacity, type and make of the protected devices.
(g) Details of glands and size of steel conduits (if applicable).
(h) The locations of the anodes and reference electrodes.
(i) The coating manufacturer should confirm that the hull coating is compatible with an impressed current cathodic protection system.

4.3.2 All impressed current anodes and reference electrodes should be capable of being replaced easily by divers.

4.3.3 Impressed current anode materials are to consist of lead/silver alloy or platinum over such substrates as titanium, niobium, tantalum or mixed metal oxide coated titanium.

4.3.4 The design and installation of electrical equipment and cables are to be in accordance with the requirements of the relevant Rules.

4.3.5 All equipment is to be suitable for its intended location. Cables to anodes are not to be led through tanks intended for the storage of low flash point products such as oils. Where cables are led through the cofferdams of storage units for volatile products they are to be enclosed in a substantial steel tube of not less than 10 mm thickness.

4.3.6 The arrangements for glands, where cables pass through shell boundaries, are to include a small cofferdam.

4.3.7 Cable and insulating material shall be resistant to chlorides, hydrocarbons and any other chemicals with which they may come into contact.

4.3.8 The electrical connection between the anode cable and the anode body is to be watertight, and mechanically and electrically sound.

4.3.9 Where electrical power is derived from a rectified a.c. source, adequate protection is to be provided to trip the supply in the event of:

(a) A fault between the input or high voltage windings of the transformer (i.e. main voltage) and the d.c. output of the associated rectifier; or
(b) The ripple on the rectified d.c. exceeding 5 per cent.

4.3.10 Suitable dielectric shields are to be fitted in order to avoid negative potentials of -1,70 volts (vs. Ag/AgCl) and below.

4.3.11 Where protection is primarily by an impressed current cathodic protection system, sufficient sacrificial anodes are to be fitted that are capable of polarising the critical regions of the structure from the time of initial immersion until full commissioning of the impressed current system.

4.4 ICCP systems for aluminium hulls

4.4.1 The use of ICCP for the corrosion protection of aluminium has a significantly higher risk of failure than ICCP used for the protection of steel vessels. However, applications for its use in fast craft such as fast ferries, sailing yachts and water jet tunnels must be considered because traditional zinc sacrificial anode cathodic protection is unsuitable for aluminium structures.

4.4.2 The accepted potential limits for the corrosion protection of aluminium hulls in clean, undiluted and aerated sea water using ICCP are as follows:

(a) Positive limit: -0,90 V (vs. Ag/AgCl)
(b) Negative limit: -1,15 V (vs. Ag/AgCl)

4.4.3 In addition to the information required for design as given in *Ch 15, 4.1 General principles 4.1.9* and *Ch 15, 4.3 Impressed Current Cathodic Protection (ICCP) 4.3.1*, the ICCP system as applied to aluminium hulls has the following additional considerations:

(a) The corrosion protection potential range must be strictly controlled and alarmed with the overprotection limit setting not to be exceeded.
(b) The ICCP is to operate within the following potential limits:

    Under-protection limit: -0,85 V (vs. Ag/AgCl)

    Overprotection limit: -1,15 V (vs. Ag/AgCl)
(c) The monitoring and control reference electrodes are to be positioned to register the maximum and minimum limits on the hull. In practice this usually means that a reference electrode should be placed near the propellers and on the periphery of the anode dielectric shield.
(d) The anode dielectric shield is to be fabricated from plastic unless an alternative coating system can be proven to maintain adhesion and dielectric properties for at least the duration of the dry dock maintenance period under the maximum operating anode voltage.
(e) The power/control and monitoring unit shall have a dielectric shield breakdown detection system capable of detecting water ingress behind the shield and current leakage through the shield. The unit should be able to detect and shut down current output automatically as well as registering an alarm. Each dielectric shield shall have an in-built sensor to detect water leakage behind the shield and current leakage through the shield.
(f) The bare marine grade aluminium (series 5000) has very low corrosion rates in open seawater and will require a current density of less than 1 mA/m^2 to fully protect it. Therefore the most suitable location of the anodes will differ from that of a steel hulled vessel. Any requirement for current density of coated aluminium can be ignored provided that the full current demand requirement for the metal underwater appendages has been taken into account.

(g) The anodes shall be located near the appendages where the current demand is at its greatest.

4.4.4 Special additional consideration needs to be undertaken to prevent bi-metallic corrosion at areas vulnerable to such attack, e.g. water-lubricated stern tubes and the underwater hull penetrations such as water cooling suctions (intakes), overboard discharges and exhaust discharges. Such considerations include:

(a) For hull penetrations, the sea valves are to be electrically isolated from hull and pipework, and the penetration depth (depth from the hull) should be less than four times the internal diameter of the penetration.
(b) For stern tubes, the wetted areas of the stern tube should be lined with a plastic tube or other sufficiently insulating material, and the shaft should have an effective passive shaft grounding system.

4.5 Sacrificial anodes

4.5.1 Sacrificial anodes intended for installation on Classed structures are to be manufactured in accordance with the requirements of this Section.

4.5.2 For offshore structures, plans showing anode nominal dimensions, tolerances and installation details are to be submitted for approval prior to manufacture.

4.5.3 For ships, anode design and details are to be agreed between the shipyard and owners.

4.5.4 When calculating the number and location of sacrificial anodes, the following items are normally considered in addition to those identified in *Ch 15, 4.1 General principles 4.1.9*:

(a) The design life of the system in years.
(b) Anode type, material and minimum design capacity of anode material, in Ah/kg.
(c) The dimensions of anodes, including details of the inserts and their locations.
(d) The nett and gross weight of the anodes, in kilograms.
(e) The means of attachment.
(f) The location of the anodes.
(g) Calculation of anodic resistance (in ohms) in the as-installed condition and when consumed to their design utilisation factor.
(h) Closed circuit potential of the anode material, in volts.
(i) Computer modelling or supporting calculations.
(j) The anode design utilisation factor.

4.5.5 The anode materials are to be approved alloys of zinc or aluminium with a closed circuit potential of at least -1,00 volt (vs. Ag/AgCl). Magnesium-based anodes may be used for short-term temporary protection of materials which are not susceptible to hydrogen embrittlement.

4.5.6 The anode material is to be cast around a steel insert so designed as to retain the anode material even when it is consumed to its design utilisation factor. The steel inserts are to have sufficient strength to withstand all external forces that they may encounter such as wave, wind, and ice loadings in the vessel or structure's normal operating conditions.

4.5.7 The anodes are to be sufficiently rigid to avoid vibration in the anode support. The steel inserts are to be of weldable, fully killed structural steel bar, section or pipe with a carbon equivalent not greater than 0,45 per cent determined using the following formula:

(a) Carbon equivalent $C_{eq} = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15$

4.6 Hybrid or combined impressed current and sacrificial anode cathodic protection system

4.6.1 The definition of the hybrid system is that it is an impressed current cathodic protection system, supplemented by sacrificial anodes.

4.6.2 If sacrificial anodes are installed on the submerged parts of a vessel or structure where impressed current is the primary cathodic protection system, then the cathodic protection should be treated as a single hybrid system and the Rules stated below are applied. The exception to this would be if the hull of a vessel is purposely electrically isolated from any of the appendages. In this case the hull and its appendages can be independently protected with either system, provided that sufficient measures are taken to prevent interference and stray current damage.

4.6.3 The design of the hybrid system should be integrated, with the impressed current and sacrificial anodes positioned so that the sacrificial anodes do not interfere with the performance of the impressed current cathodic protection system. The distances of the sacrificial anodes from the ICCP reference electrodes should not be less than three metres.

4.6.4 Where the hybrid system is installed on a vessel, the impressed current portion of the hybrid system should be designed in accordance with Section 4.3. The number, size and location of the sacrificial anodes should be sufficient to protect the aft section of the ship, without the impressed current, for a design life of one year.

4.6.5 For applications where there is a risk of anode passivation or poor performance, only zinc sacrificial anodes should be used.

4.7 Fixed potential monitoring systems

4.7.1 Offshore structures with a sacrificial anode cathodic protection system should be monitored regularly to confirm the least negative potential from the system.

4.7.2 For ships over 300 m, a permanent monitoring system is to be installed on the bow of the hull protected by an all-aft impressed current cathodic protection system. Consideration is to be given to the use of sacrificial anodes in way of known high potential zones.

4.7.3 For offshore structures, details of the monitoring system should be submitted for review.

4.8 Cathodic protection in tanks

4.8.1 Impressed current cathodic protection systems are not to be fitted in any tank.

4.8.2 Particular attention is to be given to the locations of anodes in tanks which can contain explosive or other inflammable vapour, both in relation to the structural arrangements and openings of the tanks.

4.8.3 Aluminium and aluminium alloy anodes are permitted in tanks which may contain explosive or flammable vapour, or in ballast tanks adjacent to tanks which may contain explosive or flammable vapour, but only at locations where the potential energy of the anode does not exceed 275 J. The weight of the anode is to be taken as the weight at the time of installation, including any inserts and fitting devices. The height is to be taken as the distance from the bottom of the tank to the centre of the anode but exception to this may be given where the anodes are located on wide horizontal surfaces from which they cannot fall.

4.8.4 Aluminium anodes are not to be located under tank hatches or other openings unless protected by adjacent structure.

4.8.5 Magnesium or magnesium alloy anodes are permitted only in tanks intended solely for water ballast, in which case adequate venting must be provided.

4.8.6 Anodes fitted internally should preferably be attached to stiffeners, or aligned in way of stiffeners on plane bulkhead plating. Where they are welded to asymmetrical stiffeners, they are to be connected to the web with the welding at least 25 mm away from the edge of the web.

4.8.7 In the case of stiffeners or girders with symmetrical face plates, the connection may be made to the web or to the centreline of the mild steel face plate but well clear of the free edges. Where higher tensile steel face plates are fitted, the anodes are to be attached to the webs.

4.8.8 Anodes are not to be attached directly to the shell plating of main hulls, columns or primary bracings.

4.8.9 For guidance on the design of sacrificial anode systems in tanks, *see Ch 15, 4.5 Sacrificial anodes*.

4.9 Surveys of electrical potential

4.9.1 Surveys of electrical potential in way of the submerged areas of the external hull or structure should be carried out at regular intervals.

4.9.2 Should the results of any potential survey measured with respect to a Ag/AgCl reference cell indicate values more positive than -0,8 volts for aerobic conditions or -0,9 volts for anaerobic conditions then remedial action should be carried out at the earliest opportunity.

4.10 Replacing and retrofitting of sacrificial anodes

4.10.1 Replacement and retrofitting of sacrificial anodes would preferably be carried out during dry docking. Alternatively, these operations could be carried out whilst afloat, if suitable arrangements can be made.

4.10.2 Where it is proposed to fit additional anodes, design approval is required in accordance with *Ch 15, 4.5 Sacrificial anodes 4.5.2* or *Ch 15, 4.5 Sacrificial anodes 4.5.3*.

4.10.3 Where it is necessary to weld anodes to the structure only approved welding procedures and consumables are to be used.

4.10.4 The welding procedure is to be qualified under fully representative conditions in accordance with the requirements of *Ch 12 Welding Qualifications*.

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